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INFLUENCE OF FUELS AND LUBRICANTS ON TURBINE ENGINE DESIGN AND PERFORMANCE, FUEL AND LUBRICANT ANALYSES

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Pratt and Whitney Aircraft

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An analytical study was conducted to determine the requirements for future fuels and lubricants research based on design studies of a high Mach number afterburning turbojet and a higher Mach number advanced multicycle turboramjet. Fuel and lubrication systems were defined, and computer models were developed for their thermal analyses. Fuel and lubricant stream temperature profiles were computed, and the effects of design modifications on these temperatures were evaluated. Fuel and lubricant temperatures were calculated for baseline missions, for steady-state flight envelope points, for alternate aircraft/engine interface fuel temperatures, and for transient maneuvers. Hydrotreated JP-5 fuel and MIL-L-27502 lubricant would have minimum bulk temperature capability to satisfy all these operating conditions for a Mach 3+ afterburning turbojet. Similarly, JP-7 fuel and hypothetical 500°F ester would have minimum capabilities required for the Mach 4+ turboramjet. Polyphenyl ether lubricant and JP-7 fuel are existing fluids that could be used in both applications but do not have optimum characteristics. The overall system design at each Mach number must be based on a comprehensive thermal analysis of the fuel and lubrication system to avoid constraints that could be imposed by properties of these fluids. Recirculation of fuel from the engine back to aircraft tanks was required to limit temperatures for low fuel flow transients. The engine design must use advanced technology, influenced heavily in the direction of minimum heat addition to the fuel and lubrication system. Continued effort to improve the high temperature capabilities of fuels and lubricants, in conjunction with development of advanced controls and actuation systems, continued advancements in the state-of-the-art of fluid system components, and proper thermal management of the aircraft and engine should provide the basis for future high Mach number aircraft designs that have minimum impact on fuel and lubricant logistics systems.

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INFLUENCE OF FUELS AND LUBRICANTS ON TURBINE ENGINE DESIGN AND PERFORMANCE

VOLUME II - FUEL AND LUBRICANT ANALYSES

R. L. Bucknell

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FOREWORD

This final Technical Report was prepared by Pratt & Whitney Aircraft Division of United Aircraft Corporation, P.O. Box 2691, West Palm Beach, Florida. It was submitted in accordance with item A004 of Exhibit A, Contract Data Requirements List, DD Form 1423, dated 11 June 1970, Contract F33615-71-C-1470, "Influence of Fuels and Lubricants on Turbine Engine Design and Performance." The technical work was reported for the total contract period 30 March 1971 through 30 March 1973. This report was published in two volumes to permit wider dissemination of the bulk of the work by publishing classified mission details and proprietary aircraft details separately in Volume I. These details were the bases for selections and size of engines. Volume II contains the unclassified results of thermal analyses and conclusions which are generally applicable and understandable without the Volume I details. The Contractor assigned the number FR-5673 to this report.

Contract F33615-71-C-1470 was sponsored by the Air Force Aero Propulsion Laboratory, Air Force Systems Command, United States Air Force, Wright-Patterson Air Force Base, Ohio, under Project 3048, Task No. 304806. The Air Force Project Engineer is Mr. Kerry L. Berkey (AFAPL/SFL).

Personnel from the following departments of the Pratt & Whitney Aircraft Florida Research and Development Center contributed to the technical effort described in this report: Development Engineering, Systems and Performance Analysis, Mechanical Design, and Analytical Design.

This Volume II of the report is unclassified. Volume I is classified Secret in accordance with the applicable DD Form 254, Dated 8 January 1973.

This report was submitted by the author 30 April 1973.

This technical report has been reviewed and is approved.

Howard F. Jones
Howard F. Jones, Chief
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ABSTRACT

An analytical study was conducted to determine the requirements for future fuels and lubricants research based on design studies of a high Mach number afterburning turbojet and a higher Mach number advanced multicycle turboramjet. Fuel and lubrication systems were defined, and computer models were developed for their thermal analyses. Fuel and lubricant stream temperature profiles were computed, and the effects of design modifications on these temperatures were evaluated. Fuel and lubricant temperatures were calculated for baseline missions, for steady-state flight envelope points, for alternate aircraft/engine interface fuel temperatures, and for transient maneuvers. Hydrotreated JP-5 fuel and MIL-L-27502 lubricant would have minimum bulk temperature capability to satisfy all these operating conditions for a Mach 3+ afterburning turbojet. Similarly, JP-7 fuel and hypothetical 500°F ester would have minimum capabilities required for the Mach 4+ turboramjet. Polyphenyl ether lubricant and JP-7 fuel are existing fluids that could be used in both applications but do not have optimum characteristics. The overall system design at each Mach number must be based on a comprehensive thermal analysis of the fuel and lubrication system to avoid constraints that could be imposed by properties of these fluids. Recirculation of fuel from the engine back to aircraft tanks was required to limit temperatures for low fuel flow transients. The engine design must use advanced technology, influenced heavily in the direction of minimum heat addition to the fuel and lubrication system. Continued effort to improve the high temperature capabilities of fuels and lubricants, in conjunction with development of advanced controls and actuation systems, continued advancements in the state-of-the-art of fluid system components, and proper thermal management of the aircraft and engine should provide the basis for future high Mach number aircraft designs that have minimum impact on fuel and lubricant logistics systems.

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SECTION I

INTRODUCTION

A primary objective of this study was to define fuels and lubricants research that is needed for future high Mach aircraft. Additional objectives included the presentation of data to guide engine and aircraft design, and identification of technology efforts that would permit use of selected fuels and lubricants. Fuels selected as candidates for use in the high Mach aircraft that were studied were JP-4, JP-5, JP-8, hydrotreated JP-5, and JP-7; selected lubricants were MIL-L-27502, hypothetical 500°F ester, polyphenyl ether, and perfluorinated polyether. Appendix IV lists the properties of these fluids that were used in the studies. Heat transfer and thermal properties used in calculating system temperatures were based on using MIL-L-27502 physical properties for the 500°F hypothetical ester lubricant and JP-5 fuel properties for the 500°F hydrotreated JP-5 fuel. This study included the following major steps:

1. Define the mission and aircraft used as the basis for engine requirements of future Mach 3+ and Mach 4+ interceptors.

2. Select one engine configuration each for the Mach 3+ and the Mach 4+ interceptors.

3. Prepare preliminary baseline designs for fuel and lubrication systems for each of the two engines.

4. Analytically determine fuel and lubricant temperature profiles for the baseline fuel and lubrication systems.

5. Evaluate modifications to baseline designs to minimize thermal stresses on fuel and lubricants.

6. Evaluate effects of (1) alternative fuel pump inlet temperatures, (2) steady-state flight conditions outside of the baseline missions, and (3) transient maneuvers.

7. Evaluate the use of any excess fuel heat sink to improve mission performance.

8. Perform trade studies to evaluate effects of changes in fuel and lubricant characteristics and in design concepts.

9. Define requirements for future fuels and lubricants research.

Work through Step 2 is reported in Volume I (Secret). Volume II reports all effort with the exception of classified details.

Effects of the selected fuels and lubricants on aircraft mission capabilities and engine characteristics were identified so that requirements for future fuels and lubricants research could be recommended. Because of the high environmental and high engine cycle temperatures in the two applications investigated,

realistic mission requirements, coupled with state-of-the-art aircraft designs, engine designs, and fuel and lubrication system designs, were defined and analyzed to accurately identify capabilities and limitations of the specified combinations. Using these advanced designs, the fuel and lubricant temperature profiles within the engines were generated. Alternative operating conditions and alternative design approaches were investigated to determine the need for fuel and lubricant research and technology that should be conducted to provide the basis for aircraft/engine development programs for high Mach number interceptors.

Thermal analyses to determine limitations of the fuels and lubricants included consideration of the heat sink of the fuel delivered to the engine, the environmental heating encountered, and the internal heat generation of fuel and lubrication system components. The heat sink of the fuel is affected by such factors as the type of fuel, the fuel flowrate, and prior heating of the fuel by aircraft heat loads. These relationships necessitated definition of the mission flight profile, the aircraft configuration, and the engine size, design, and performance. The fuel and lubrication systems for the two propulsion systems under study were identified, including physical arrangement, time variant flowrates, component efficiencies, pressure, surface areas, volumes, and thermal environment. Thermal conditions of fuel and lubrication systems, fuel and lubricant selections, and baseline modifications to overcome limitations were evaluated.

Computed fuel and lubricant temperatures were compiled and reviewed for (1) the baseline mission, (2) alternate interface temperatures of 150°F, 250°F, and 350°F, (3) bearing compartment hot spots, (4) transient ("throttle-chop") maneuvers, and (5) representative points outside the baseline mission but within the flight envelopes, for alternate interface temperatures. Fuel and lubricant temperature differences were also reviewed for alternate (1) lubricant distribution, (2) fuel manifolding and nozzle arrangements, and (3) supplementary fuel cooling concepts. Comparisons were made with the J58 engine level of technology, the current state-of-the-art and that projected for the 1980's, showing significant potential reductions in heat loads using advanced controls and actuation system concepts. The resulting operating requirements for fuels and lubricants, particularly the thermal stability requirements, were compared with capabilities of the fuels and lubricants defined as candidates under this program. This led to identification of limitations within the current state-of-the-art and the recommended research programs that should provide a cost-effective balance between advanced technology for fuels, lubricants and system components.

SECTION II

SUMMARY

A study of fuel and lubricant requirements for future high Mach number aircraft was completed. The initial task was to define the operating requirements, operating parameters, and operating conditions for fuel and lubrication systems, based on selections of appropriate engines and flight conditions for Mach 3+ and Mach 4+ interceptor aircraft. USAF contract studies were the basis for missions and aircraft configurations that the engines were to satisfy, as follows:

- F33615-71-C-1014, Quick Response Interceptor Study, conducted by Vought Aeronautics

- F33615-69-C-1388, Comparative Propulsion System Concepts Study, conducted by McDonnell Douglas.

Aircraft characteristics and mission requirements were combined with characteristics of candidate propulsion systems in mission analyses computer programs to select the most appropriate engines. The STJ346A afterburning turbojet study engine (incorporating estimated 1978 technology levels) was selected for the Mach 3+ twin engine interceptor on the basis of a lower fuel plus propulsion system weight than the competitive STF378 duct heating turbofan. For the Mach 4+ twin engine interceptor, the STRJ334B turboramjet (incorporating estimated 1980 plus technology levels) gave a lower aircraft gross takeoff weight (GTOW) than either the STFRJ335 or STFRJ368 turbofan-ramjets. The selected engines were sized to provide the minimum GTOW that would meet the respective mission requirements.

Schematics were prepared for several alternate fuel and lubrication systems for each engine. These were evaluated to select the most suitable baseline configurations. The final configurations included (1) electronic controls, (2) variable delivery main fuel pumps without boost stages, (3) air turbine-driven afterburner/ramjet fuel pump, (4) no hydraulic actuation systems, (5) minimum environmental exposure, (6) gearboxless accessory drives for the turboramjet, and other features to reduce heat absorption/generation. Installation designs, component characteristics and computer thermal models were prepared for the fuel and lubrication systems of the STJ346A and STRJ334B engines. Aircraft fuel tank temperatures and aircraft heat loads rejected to the fuel system were based on McDonnell Douglas estimates for the baseline missions. Use of insulated structural concepts maintained aircraft heat loads for the Mach 4+ interceptor at approximately the same levels as those for the Mach 3+ configuration. Aircraft fuel tank temperature, aircraft heat load, environmental heat, engine heat generation, and fuel and lubrication system characteristics were combined in the computer model to provide a means to rapidly and accurately calculate fuel and lubricant stream temperature profiles.

The next task was to evaluate the baseline system temperatures for the two baseline missions. Initial lubricant stream temperature profiles showed that modifications should be made to the baseline lubrication systems to revise oil flowrates to the bearing compartments for more effective use of the lubricant heat capacity. Additionally, insulation was added to bearing compartments and conductive heat paths were minimized to reduce locally high lubricant temperatures.

Modifications to reduce short duration peaks in fuel temperature in the engines were also indicated. An alternate mode of engine operation during a turn maneuver was shown to be one approach to eliminate fuel overtemperature, and recirculation of fuel to the airplane also prevented fuel overtemperature during transient maneuvers without restricting operating flexibility. Accordingly, the baseline operating procedure was modified to eliminate the reduced power setting during the turn, and a fuel recirculation loop was included in the baseline fuel system.

Using the revised baseline fuel and lubrication systems, the baseline definition of fuel tank temperature profile, aircraft heat load, and mission flight conditions, the maximum STJ346A fuel temperature was calculated to be 325°F. The corresponding maximum fuel temperature for the STRJ334B was 515°F. With these baseline definitions of fuel temperature profiles for mission flight conditions, the maximum STJ346A lubricant temperature was calculated to be 345°F and the maximum STRJ334B lubricant temperature was 385°F.

The next task was to investigate the effects of alternatives to the baseline aircraft and mission characteristics. These investigations covered: (1) alternative engine fuel pump inlet temperatures, (2) steady-state flight conditions within the operating envelopes of the two engines that were not a part of the baseline missions, and (3) transient conditions (throttle-chop at high Mach numbers) that would impose the maximum heat load on the fluid systems.

For the STJ346A, maximum altitude and Mach number for flight envelope cruise conditions at alternate aircaft/engine interface fuel temperatures showed maximum fuel temperatures of 225°F for 150°F interface, 310°F for 250°F interface, and 395°F for 350°F interface fuel temperature. Corresponding lubricant temperature maximums were 260, 330, and 425°F. Steady-state flight in the flight envelope, but outside the baseline mission, was calculated to require fuel temperature capability up to 500°F, and bulk lubricant temperature of 425°F, based on operation at the high altitude, low Mach number side of the flight envelope. With use of fuel recirculation (return of fuel from engine to aircraft tanks) and aircraft tank fuel temperature of 250°F or less, transient fuel temperatures were limited to less than 400°F during transient maneuvers. Transient maneuver conditions of low fuel flow had little effect on lubricant temperature due to thermal lag from the heat capacity of the lubrication system.

Fluids having minimum bulk temperature limits that could satisfy all the above operating conditions for the STJ346A engine would be hydrotreated 500°F JP-5 fuel and MIL-L-27502 lubricant. Baseline mission conditions could have been satisfied with JP-5 fuel, although this would eliminate capabilities for transient maneuvers and steady-state flight throughout the full envelope.

For the STRJ334B, maximum altitude and Mach number cruise flight conditions at alternate aircraft/engine interface fuel temperatures showed maximum fuel temperatures of 430°F for 150°F interface, 485°F for 250°F interface, and 550°F for 350°F interface fuel temperature. Corresponding lubricant temperature maximums were 325, 360, and 450°F. These were found to be the most severe fuel and lubricant temperature requirements of the entire STRJ334B flight envelope for steady-state cruise. A "throttle-chop" transient at cruise Mach number resulted in a calculated fuel temperature maximum of 800°F; however, recirculation flow was shown to be a means to reduce this below 600°F. The "worst case" theoretical transient bulk lubricant temperature was computed to be 522°F; however, system thermal lag would reduce the actual value, as would additional fuel recirculation, so that this condition would be less severe than the worse steady-state values.

Fluids having minimum bulk temperature limits that could satisfy all the above operating conditions for the STRJ334B turboramjet would be JP-7 fuel and hypothetical 500°F ester lubricant. Similar to the findings for the lower Mach number STJ346A engine, significantly lesser fuel and lubricant capabilities were needed for the baseline mission than those needed to provide operating flexibility for alternate maneuvers and broader flight envelope conditions.

Parametric curves of fluid temperatures were prepared to allow estimates of fuel and lubricant temperatures as a function of varying aircraft tank temperature, aircraft heat loads, other interface temperatures, and alternate fuel recirculation rates. These are presented for transient maneuvers and steady-state (engine thrust equals aircraft drag) flight envelopes.

Supplementary systems to use the excess heat sink that is available when JP-7 fuel is used were studied for the STJ346A and STRJ334B engines. Fuel cooling of engine cooling air can reduce the required flow of cooling air for either engine; however, the resulting reductions in engine fuel consumption were less than 1/2% and not sufficient to offset the added weight and complexity of the required fuel/air heat exchanger systems (STJ346A: 90 lb and STRJ334B: 225 lb). These systems would have increased maximum fuel temperatures to 600°F and were not included in the final system designs.

Comparisons of the STJ346A fuel and lubrication systems were made with the J58 engine at comparable operating conditions. The very significant reductions in fluid system temperatures in the 1978 study engine compared to those in the J58 were shown to be associated with advancements in the state-of-the-art of engines and components that have essentially been demonstrated. This comparison illustrates the importance of emphasizing fuel and lubricant thermal considerations in the initial design of future high temperature engines.

Studies were completed of the effects on fuel and lubricant temperature if the STRJ334B baseline design were changed from advanced air-turbine to hydraulic actuation systems similar to those in use on today's engines. Fuel temperature for the STRJ334B would be increased approximately 40°F for cruise operating conditions and up to 300°F for the transient descent condition. Corresponding increases in lubricant temperature of 65 and 250°F(transient) were calculated, illustrating the importance of future advancement in the state-of-the-art of engine variable geometry actuation systems.

The results of this study were based on fuel and lubrication system designs optimized to minimize fuel and lubricant temperatures. Required component technology is virtually in hand for the STJ346A afterburning turbojet design, based on experience gained with the J58 engine and updated with advancements in technology developed for the F100 engine. Since a fuel of 500°F bulk temperature capability is adequate, operating costs could be reduced by development of a fuel of a lower cost than JP-7, such as the hypothetical hydrotreated JP-5. Completion of the development of a lubricant meeting MIL-L-27502 specifications is required. The approximately 700°F higher environmental temperatures for the STRJ334B turboramjet necessitate continued advancements in the techniques of thermal management, insulation, bearing compartments, gearboxless accessories, controls sensors, electrical wiring, electronic controls, controls interfaces with components, and variable-geometry actuation systems. The estimated projections of the technology in these areas have shown that a Mach 4+ aircraft in the early 1980's will require development of a 500°F lubricant or use of polyphenyl ether, which requires dilution to reduce viscosity at low temperatures. Upgrading of existing fuel and lubricant temperature capabilities should be continued in conjunction with engine technology efforts. This complementary approach should produce a satisfactory high temperature weapon system with minimum impact on existing logistics facilities.

SECTION III

LOW MACH NUMBER ENGINE STUDY

A. ENGINE SELECTION

Evaluation of the influences of fuels and lubricants on a next generation Air Force Mach 3+ interceptor required definition of representative designs for the aircraft and engines, their operating conditions, and a complete design definition of the fuel and lubrication system for the engines. The first tasks were the definition of a representative interceptor mission and corresponding aircraft characteristics. USAF Contract F33615-71-C-1014 studies of the Quick Response Interceptor (QRI), performed by Vought Aeronautics, were used as the basis for the typical interceptor mission described in Volume I. The mission consisted of a required high rate of acceleration to cruise, Mach 3+ cruise, combat maneuvers, cruise back at Mach 3+, descent, and nominal loiter before landing. USAF Technical Report No. ASB70-12 ASB/MAD, prepared under the same Vought Aeronautics contract, also provided the aircraft configuration, lift, and drag characteristics (contained in Volume I) that were used to determine appropriate engine type and size.

The candidate Pratt & Whitney Aircraft (P&WA™) study engines for the mission were the STJ346A afterburning turbojet and the STF378 duct heating turbofan. The computer program used to compare and size the engines was developed at P&WA while supporting Vought Aeronautics with engine information. A block diagram of the computer program is shown in figure 1. Installed engine and mission performance was obtained by modification and utilization of portions of the REAPS computer programs generated on the APSI program (Contract F33657-69-C-0270). The program calculates fuel plus propulsion weight, based on fixed-aircraft size and weight in performing a specified mission; iteration to adjust aircraft size and engine size are omitted for economy. However, the resulting approximation of engine plus propulsion weight provides a reasonable weight optimization indicator (WOI) as a basis for selecting one of several engines that minimize aircraft weight. The criteria for determining the minimum airflow size of each of the candidate engines included the intercept time and power required for the mission turn. The thrust for a turn required two 277 lb/sec STJ346A afterburning turbojet engines, and the intercept time sized two STF378 duct heating turbofan engines at 346 lb/sec.

The most significant operating advantages of the STJ346A are reduced weights of fuel consumed during climb and cruise, and reduced inlet weight for the lower airflow engine. The primary advantage of the turbofan engine was lower fuel consumption during the loiter, but this was not a determining factor in the engine selection.

The STJ346A afterburning turbojet engine was selected on the basis of the lowest fuel plus propulsion system weight that satisfied the mission requirements. This result is shown in figure 2, which compares the influence of engine design airflow on the fuel plus propulsion system weight for the two candidate engines.

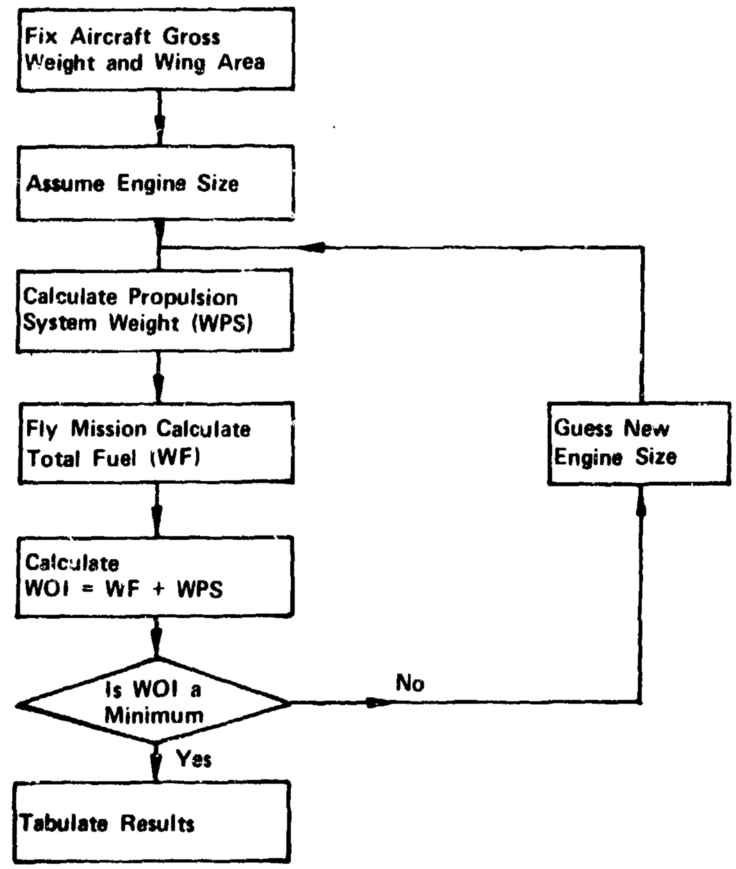


Figure 1. Low Mn Aircraft/Engine Sizing Procedure

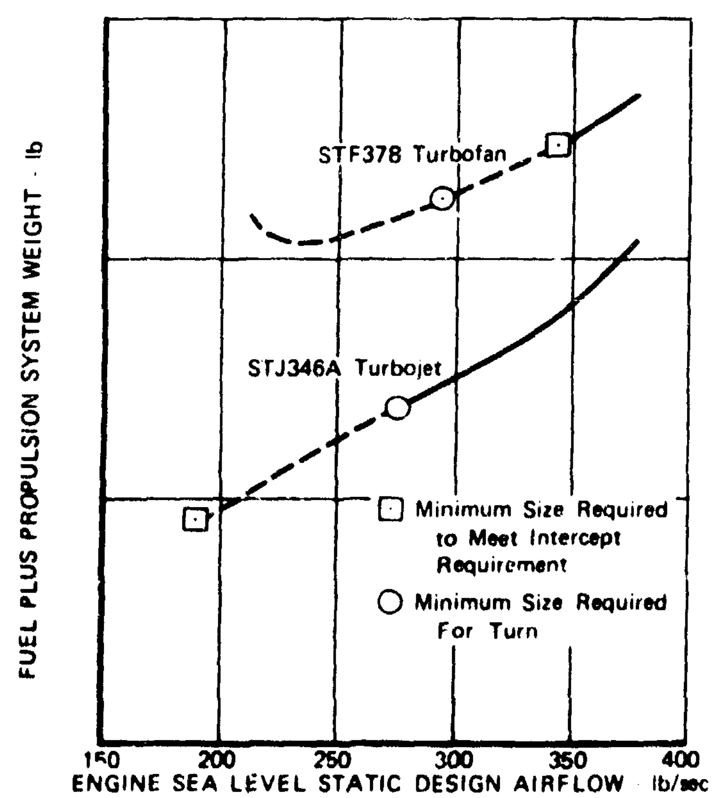


Figure 2. Engine Comparison for the Low Mn Mission

B. STJ346A AFTERBURNING TURBOJET DESCRIPTION

The STJ346A engine was selected from the candidate FRDC study engines for the Mach 3+ part of this fuels and lubricants influence study. The basis of the selection was the lowest fuel plus propulsion system weight that satisfied the mission requirements. Twin 35,000-lb sea level thrust-size engines were consistent with aircraft characteristics and mission requirements, including thrust required for rapid acceleration and high "g" turn.

The STJ346A is an afterburning turbojet designed to provide high propulsion performance at speeds above Mach 3. Figure 3 provides a cross section showing the arrangement of the major components in this engine, which was designed for application in 1978. The engine has a single-spool, eight-stage compressor with a pressure ratio of 12:1. The design incorporates a drum rotor, cantilevered stators, and variable stator geometry. The primary combustor is an annular, premixed, vaporizing burner with a maximum combustor discharge temperature of 2700°F. A single-stage turbine drives the compressor. Advancements in materials, cooling techniques, and aerodynamic technology permit operation of this single-stage turbine to 2700°F TIT. The afterburner will operate at high temperatures (3800°F), requiring advanced fuel injection and flameholder concepts. The higher afterburner inlet temperature (turbine discharge temperature) of the STJ346A engine will promote spontaneous ignition of the fuel and require development of sprayring and flameholder concepts. A variable-area, convergent-divergent nozzle was incorporated for maximum high Mach number efficiency. Major STJ346A engine parameters are summarized in figures 4 and 5.

C. STJ346A FUEL AND LUBRICATION SYSTEM DESCRIPTION

The fuel and lubrication system selected as the baseline concept for the Mach 3+ STJ346A afterburning turbojet was based on a composite of the Pratt & Whitney Aircraft Mach 3+ J58 engine (operational), the F100/F401 engines (current development program), and current advanced development component technology. The system should, therefore, provide realistic evaluation of fuel and lubricant limitations consistent with the best capabilities that can be anticipated for next generation, high Mach number applications (1978 time frame). The baseline fuel and lubrication system has the following key features:

- Operationally and experimentally verified lubrication system arrangement
- Supplementary oil cooling by auxiliary fuel/oil cooler
- Accessibility of components for installation and maintenance
- Minimum parasitic heat generation for variable-delivery fuel pumps
- Conventional gearbox drive of airframe and engine accessories
- Fuel metering and control mechanisms not exposed to high fuel temperatures

- Reduced heat loads for engine with air-actuated, variable geometry and two-bearing configuration

- Weight and volume penalties to provide desirable control system redundancy, flexibility, and high accuracy are minimized by use of an electronic control

- Effective insulation for bearing compartments and fluid system components exposed to high temperature.

The physical locations and configurations for the components of the STJ346A fuel and lubrication system are shown in figures 6 and 7. A schematic showing the flowpaths and integration of the airframe/engine fuel and lubrication systems is provided in figure 8.

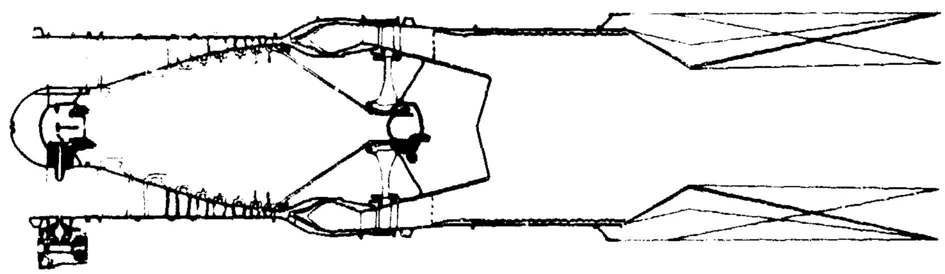


Figure 3. STJ346A Afterburning Turbojet Cross Section

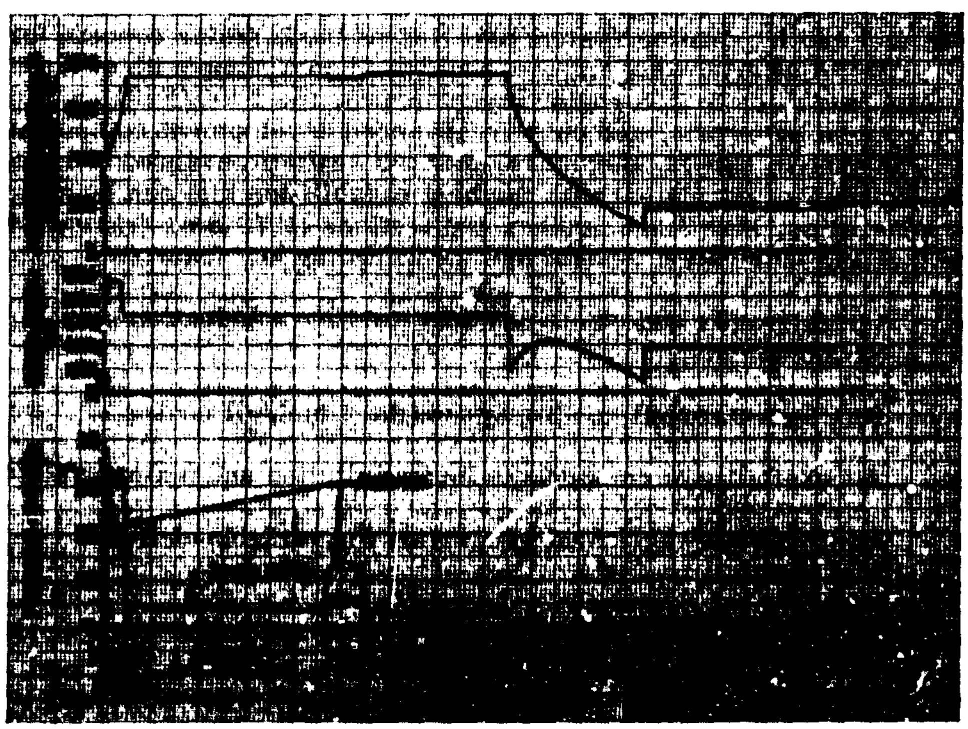


Figure 4. STJ346A Operating Parameters During the Low Mn Mission

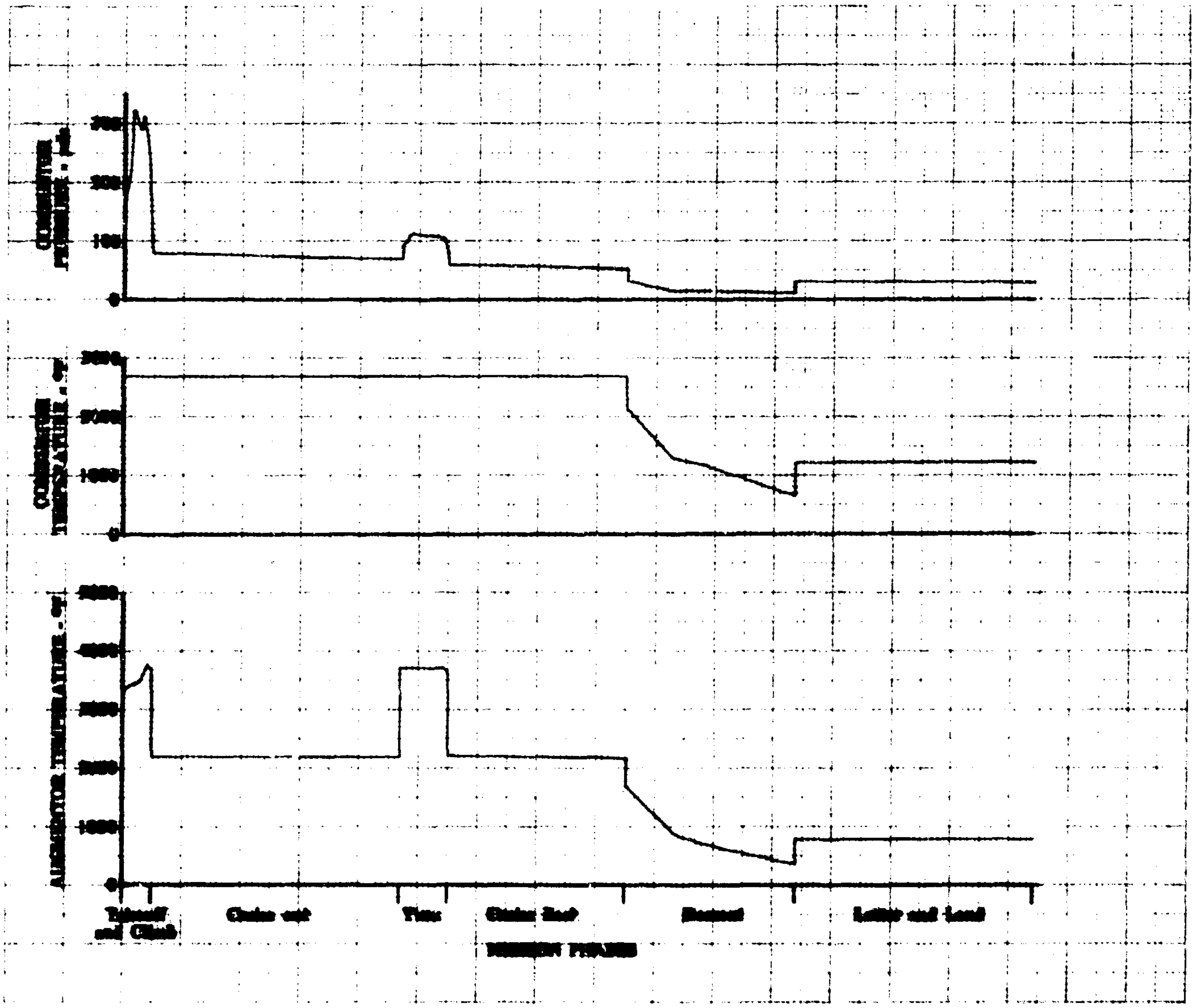


Figure 5. STJ346A Operating Parameters During the Low Mn Mission

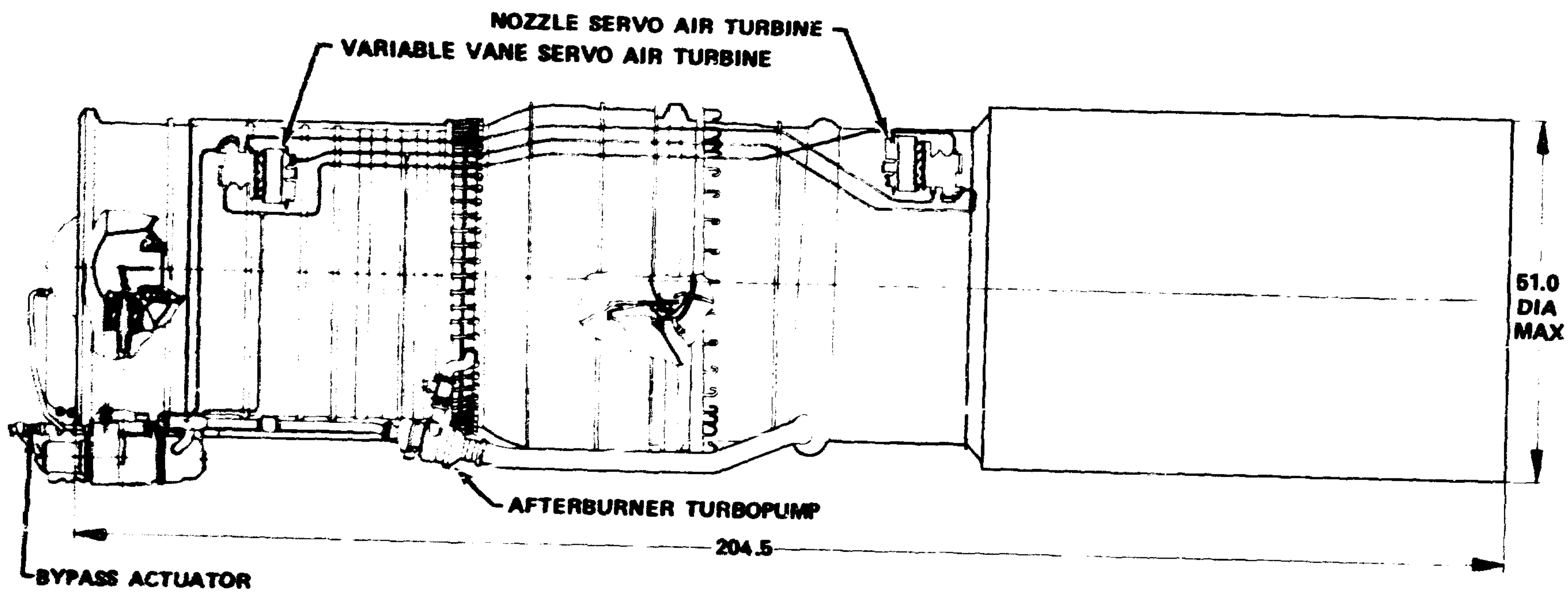


Figure 6. STJ346A Fuel and Lubrication System, Left-Hand Side

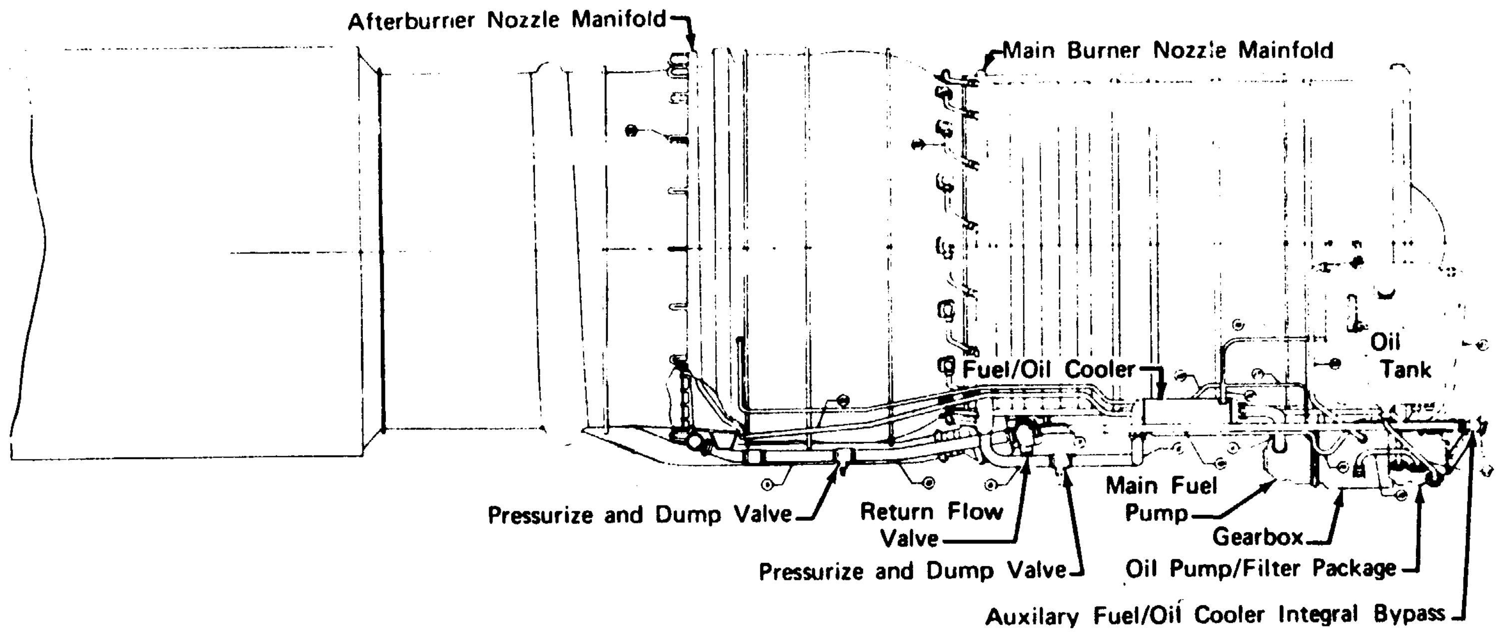


Figure 7. STJ346A Fuel and Lubrication System, Right-Hand Side

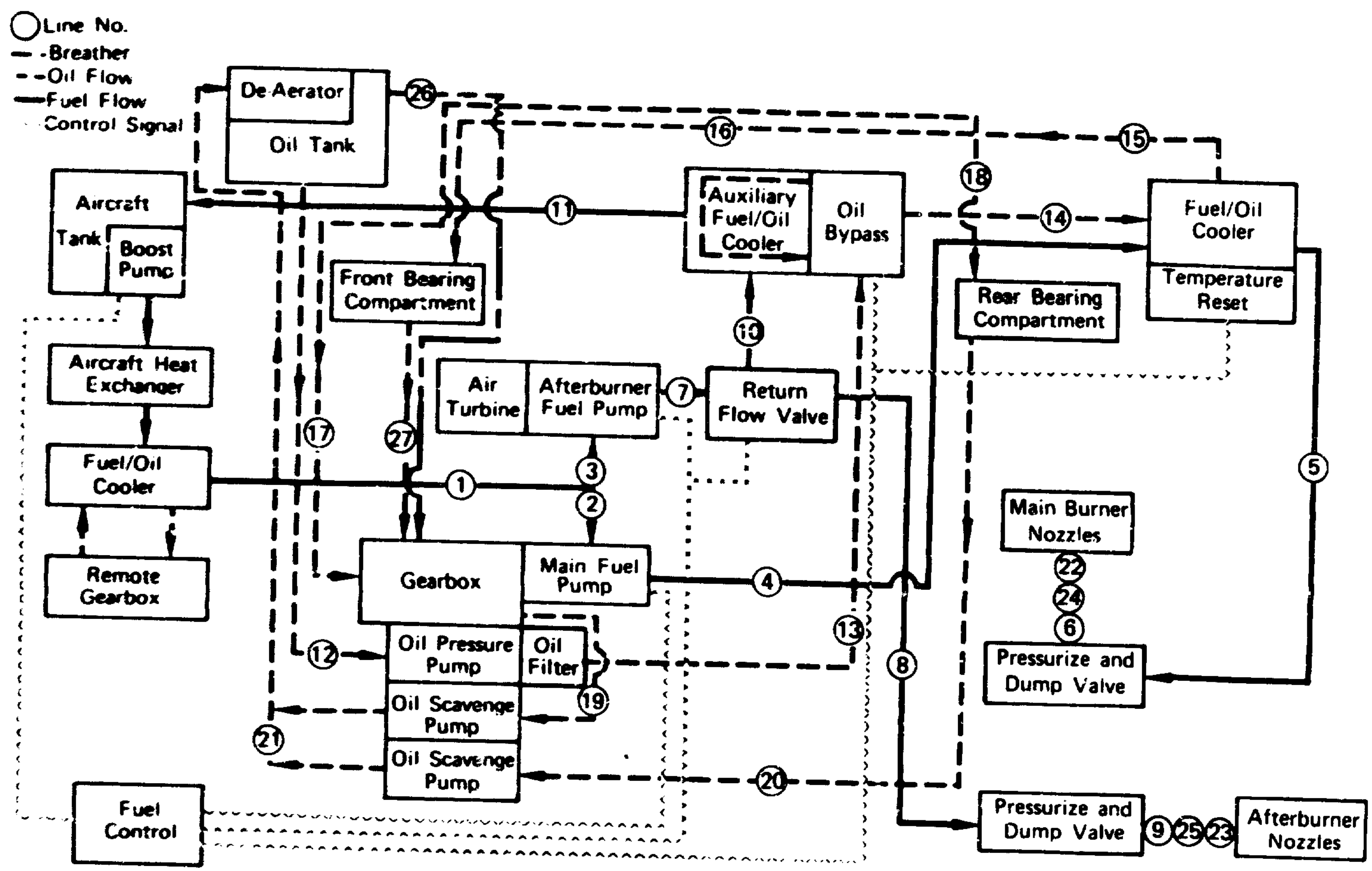


Figure 8. STJ346A Fuel and Lubrication System Schematic

1. Fuel System Operation and Arrangement

The baseline fuel system meters the desired flows to the main combustor and afterburner of the STJ346A engine. This system also provides the heat sink to cool the engine lubrication system and airframe systems. Features that should contribute to reduced system temperatures are (1) variable delivery pumps to minimize heat generation, (2) an electronic control that eliminates complex hydromechanical components, and (3) an air actuation system instead of a fuel hydraulic system for engine variable geometry.

The aircraft fuel tank boost pump provides adequate pressure to deliver fuel through the aircraft heat exchangers and the remote gearbox fuel/oil cooler to the engine fuel pumps. The following description of the operation and arrangement of the STJ346A afterburning turbojet fuel system is referenced to figure 8:

- The engine fuel inlet (line 1) divides to supply the engine main pump (line 2) and the afterburner pump (line 3).

- The main fuel pump is a direct gearbox-driven, variable-displacement vane pump that is controlled to supply flowrates up to 52,000 lb/hr upon demand of the engine

- From the main fuel pump, fuel passes (line 4) through the main fuel/oil cooler to the main burner pressurizing and dump valve (line 5), where manifolds (lines 6, 22, and 24) distribute the flow to the nozzles. For extreme or unusual operating conditions, the main engine fuel flow may not provide sufficient heat sink for the engine cooling requirement. An oil or fuel overtemperature would then activate a temperature reset to initiate supplementary oil cooling by the afterburner fuel system.

- The afterburner centrifugal fuel pump is driven by an engine-bleed-air turbine. Turbine/centrifugal pump speed is controlled to supply the flow required (line 7) for the engine plus a nominal bleed (line 10) to prevent stagnation of the aircraft return flow line (line 11). During afterburner operation the required fuel flow is supplied (line 8) to the pressurizing and dump valve and distributed to the afterburner fuel nozzles by manifolds 9, 23, and 25.

- When the afterburner is not operating, fuel lines 8, 9, 23, and 25 must be cleared to preclude coking of stagnated fuel in the hot environment. The pressurizing and dump valve is used to purge fuel from lines between the return flow valve and afterburner. A minimum flow is maintained through the afterburner pump and returned through the return lines 10 and 11 to the aircraft tank to prevent coking in the pump and tank return line. The tank return line provides for aircraft and lubrication system cooling for operating conditions of high heat load but low engine fuel flow demand. Fuel flow through the auxiliary fuel/oil cooler in the tank return line can be

increased and lubricant diverted through this cooler to provide additional cooling during an operating condition such as idle descent. Lubricant bypasses this auxiliary cooler during normal nonafterburning operation to preclude overtemperaturing of afterburning cooling fuel flow.

2. Fuel System Components

The STJ346A main fuel pump shown in figure 9 is a variable displacement vane pump driven by the gearbox. The pump has a capacity of 52,000 lb/hr at 4,000 rpm.

The afterburner fuel pump, figure 10, is a centrifugal turbopump designed for operation on compressor bleed airflow. The pump capacity is 65,000 lb/hr at 500 psi and 32,000 rpm.

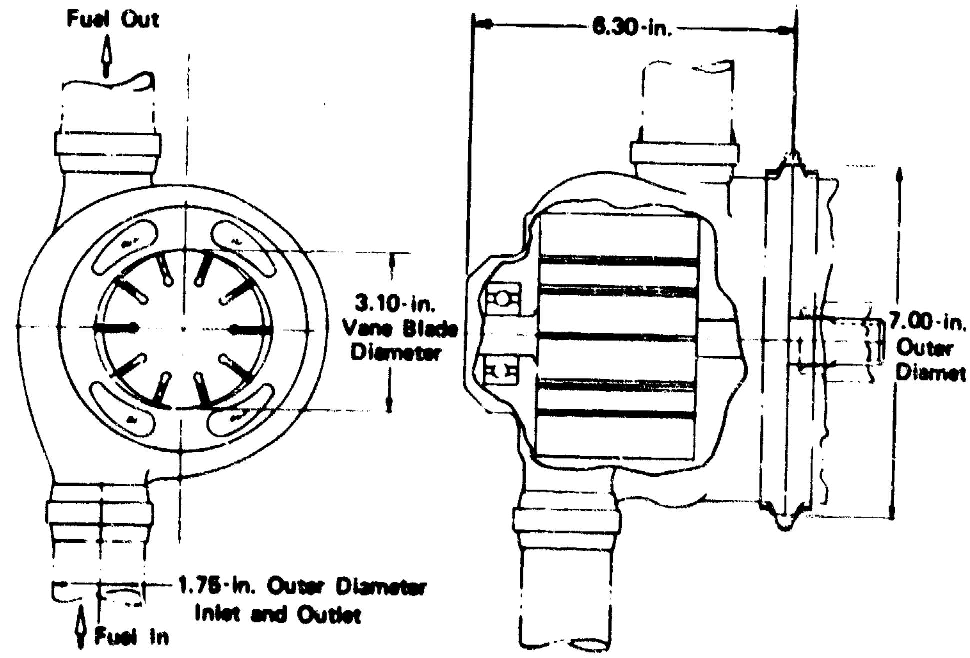


Figure 9. STJ346A Variable Displacement Main Fuel Pump

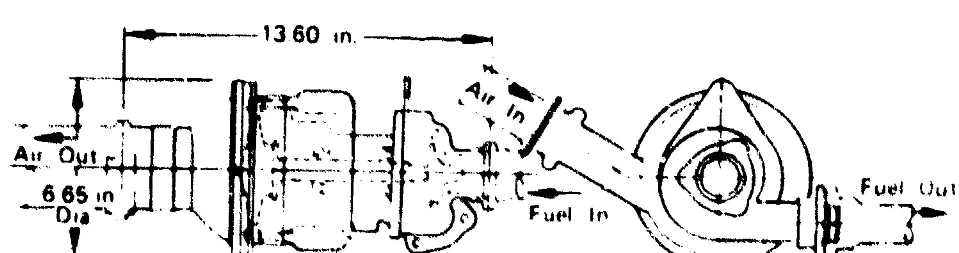


Figure 10. STJ346A Afterburner Fuel Pump

The fuel/oil heat exchanger shown in figure 11 is a shell-tube type. Fuel flows through tubes from headers on each end while oil is cooled by following a labyrinth passage around the fuel tubes. Temperature probe bosses are incorporated for integration with the control system, the auxiliary fuel/oil cooler, and the afterburner fuel pump.

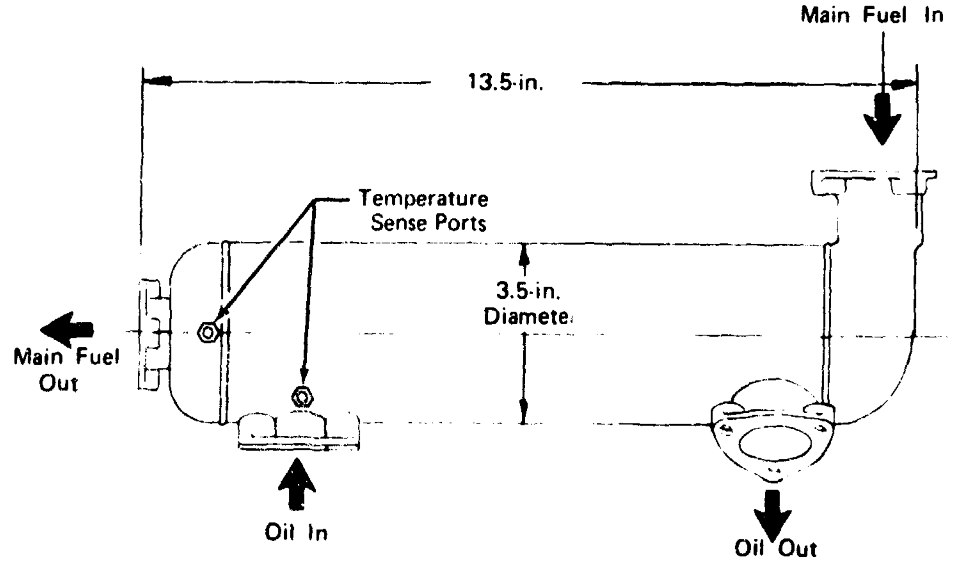


Figure 11. STJ346A Fuel/Oil Heat Exchanger

The auxiliary fuel/oil cooler shown in figure 12 is smaller, but similar to the main fuel/oil cooler. The major difference is an integral bypass on the oil side. This bypass is necessary to eliminate fuel heating when the auxiliary oil cooling feature is not required for engine operation. It also prevents stagnation of the oil and overpressurization of the cooler when it is not in use.

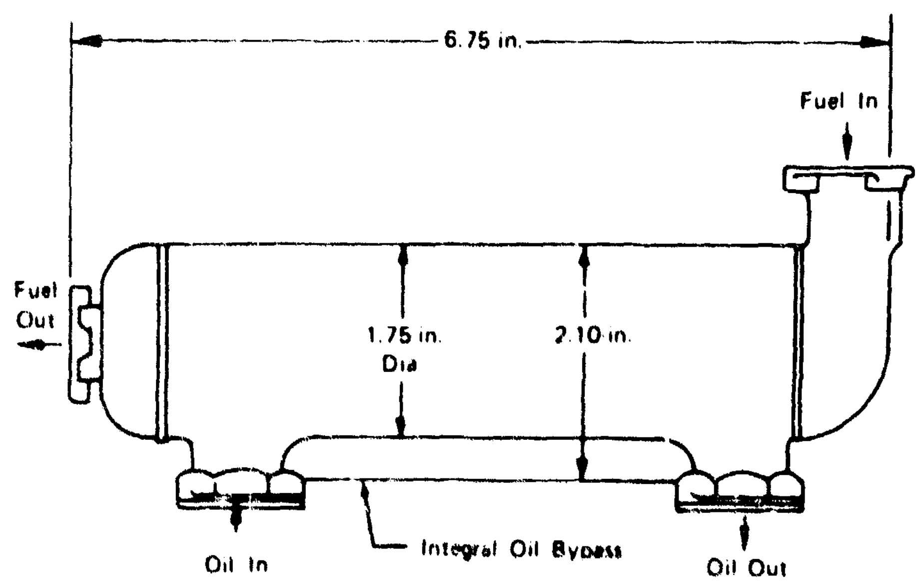


Figure 12. STJ346A Auxiliary Fuel/Oil Cooler

Appendix II contains performance data for components that were used in thermal analyses.

3. Lubrication System Operation and Arrangement

The baseline lubrication system provides lubrication and cooling for the two bearing compartments, figures 13 and 14 (subsequently modified to improve insulation as shown in figures 30 and 32), and the engine gearbox, figure 15, of the STJ346A afterburning turbojet engine. Lubricant is supplied from the oil tank to the main oil pump, which is driven from the main gearbox. The pressurized lubricant is then filtered and in normal operation directed through the main fuel/oil cooler to the engine bearings and gearbox. To preclude oil and fuel overtemperature at occasional operating points of low fuel flow and high heat loads, the bypass integral with the auxiliary fuel/oil cooler will direct lubricant through the auxiliary fuel/oil cooler before it flows through the main fuel/oil cooler. The following description of operation and general arrangement refers to the line identification numbers shown in figure 8.

- Gravity flow supplies oil from the tank to the pressure supply pump (line 12).

- The oil pressure pump is part of a gearbox-driven package that includes the oil scavenge pumps and filter. This package provides a compact assembly that is readily adaptable to effective insulation. Oil from the filter (line 13) flows to the bypass of the auxiliary fuel/oil cooler and then to the main fuel/oil cooler (line 14). During normal engine operation, no heat is transferred in the auxiliary fuel/oil cooler. Oil cooling is provided by the main fuel/oil cooler except for occasional operation at low engine fuel flows when the fuel consumption may be too low for adequate oil cooling. High fuel or oil temperature activates a temperature reset to direct the bypassed oil through the auxiliary fuel/oil cooler, and the afterburner turbopump fuel return flowrate is increased to prevent an overtemperature in the aircraft return line. When the engine is in the afterburning mode, the oil is not directed through the auxiliary fuel/oil cooler as the main engine fuel/oil cooler is sufficient to meet the cooling requirements.

- The oil flow out of the main fuel/oil cooler (line 15) divides to supply the front bearing compartment (line 16), the rear bearing compartment (line 18), and the gearbox (line 17).

- Oil scavenge from the front bearing compartment drains through the tower shaft passage (line 27) to the gearbox. The combined front bearing compartment and gearbox oil flows (line 19) are scavenged by one pump. The rear bearing compartment drains (line 20) to the second scavenge pump. The combined scavenge is returned to the tank by line 21. The rear bearing compartment breather air is combined with the scavenge oil (line 20) and transferred to the oil tank through the deaerator. The oil tank vents the breather (line 26) to the gearbox, which includes a deoiler and breather discharge.

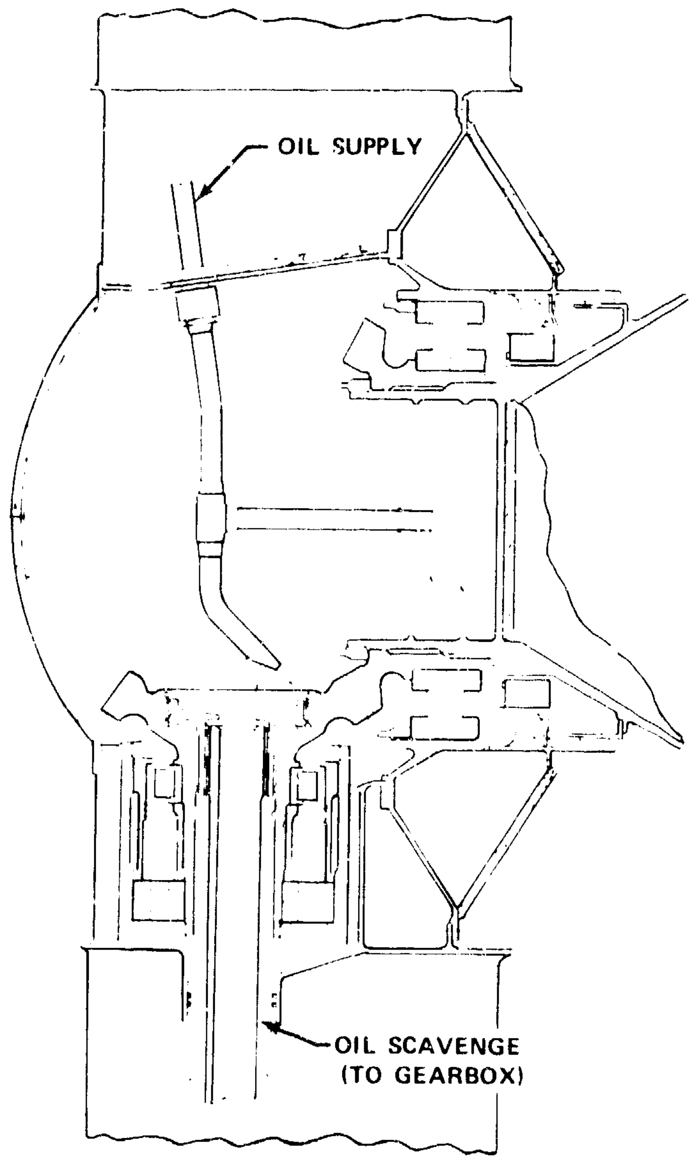


Figure 13. STJ346A Front Bearing Compartment

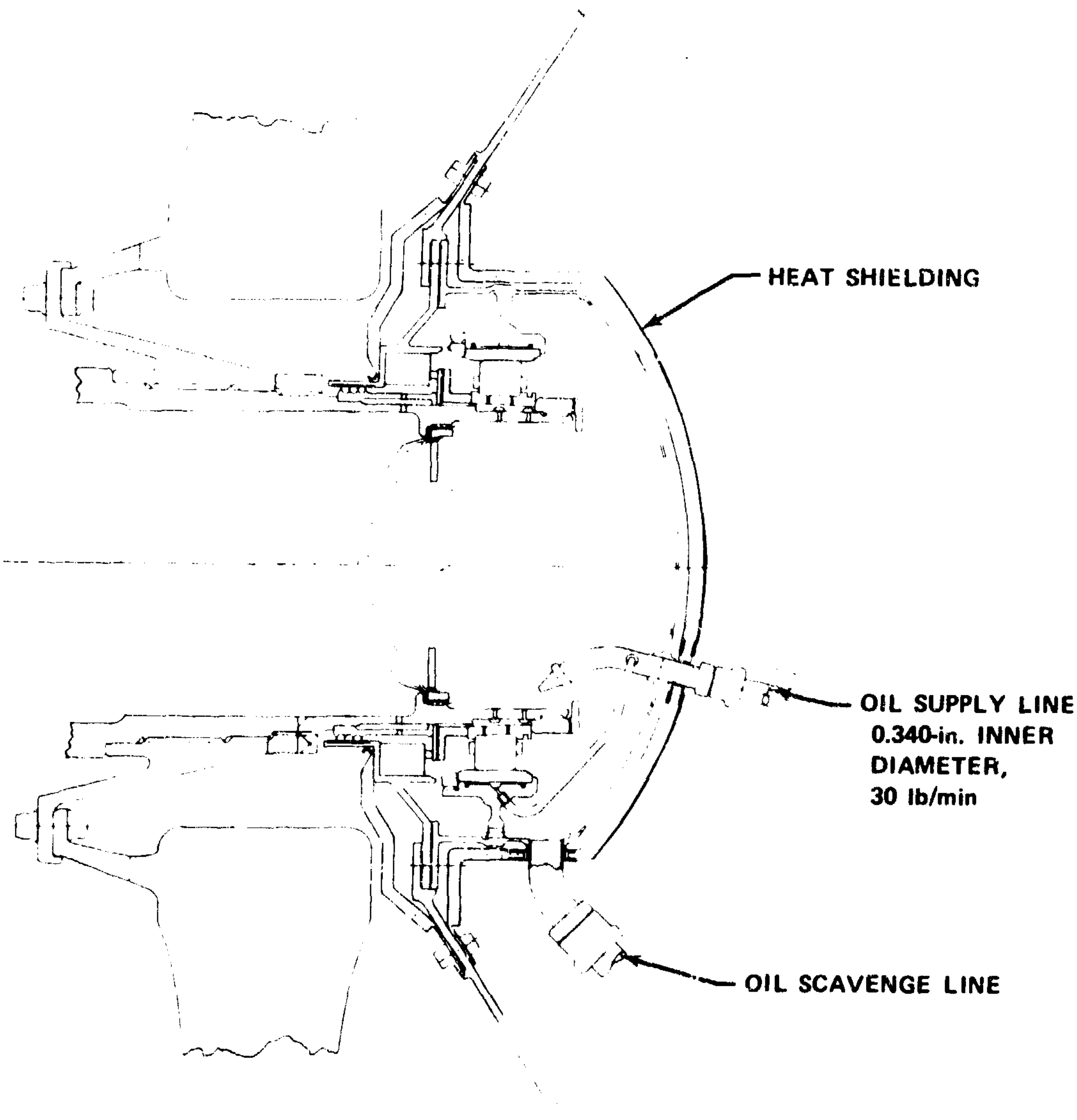


Figure 14. STJ346A Rear Bearing Compartment

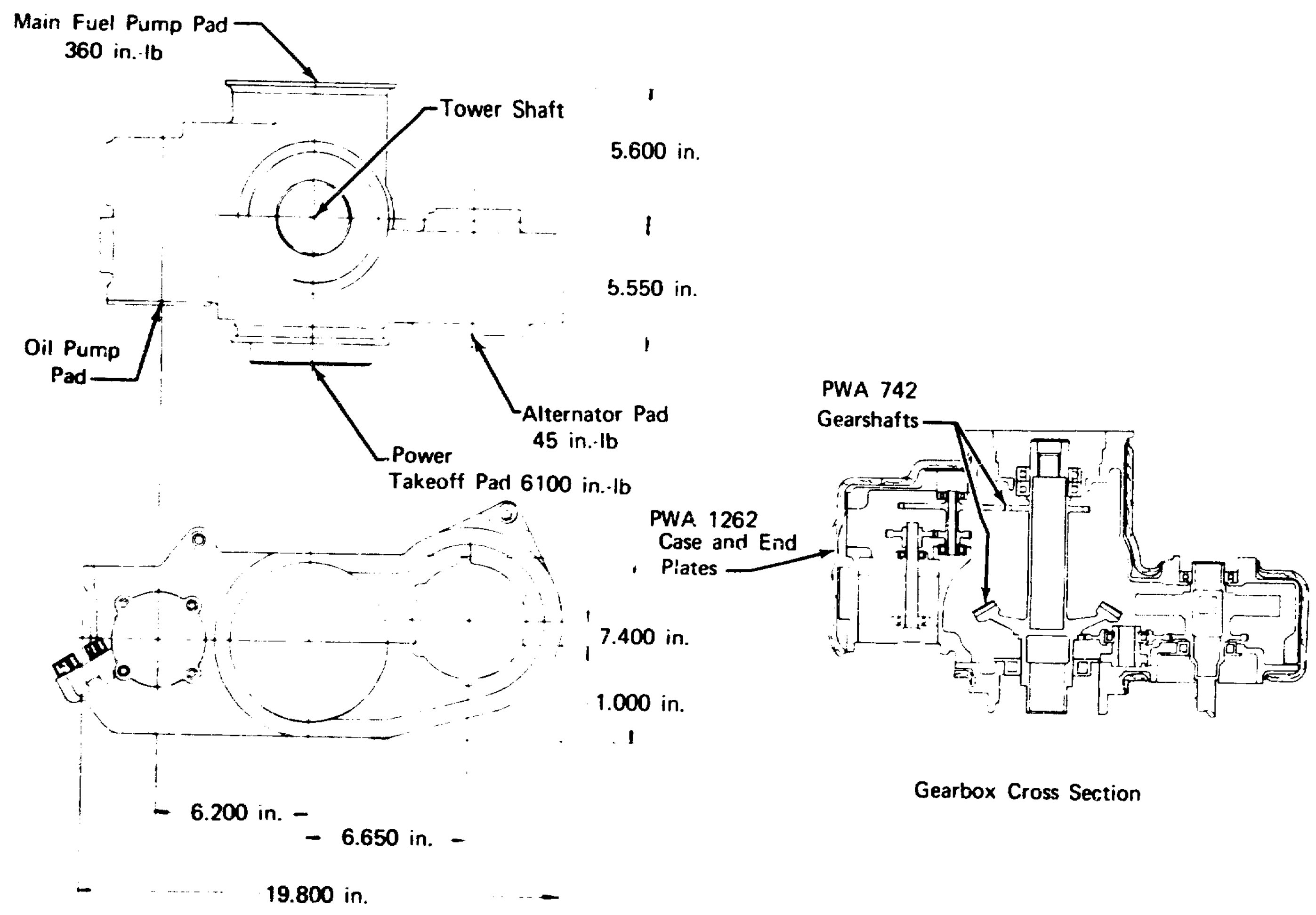


Figure 15. STJ346A Gearbox

4. Lubrication System Component Descriptions

The STJ346A oil tank, shown in figure 16, was designed for a 5-gal volume. A deaerator is installed in the tank inlet system and is oriented to preclude siphoning. Provisions are made for gravity fill, remote fill, remote drain, and a breather line, in addition to inlet and outlet for normal lube system operation.

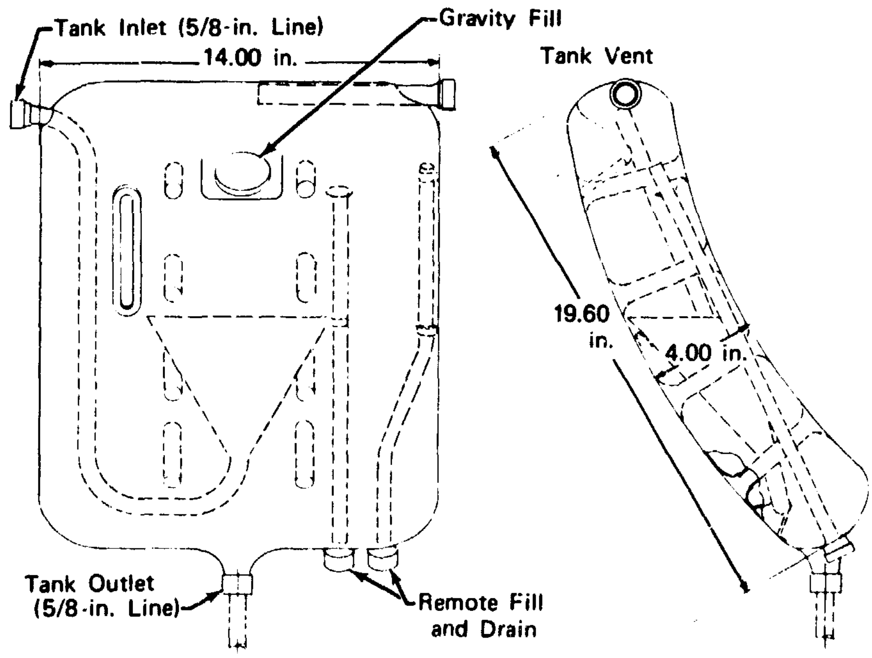


Figure 16. STJ346A Oil Tank

The oil pump and filter assembly, shown in figure 17, has two scavenge pumps, one pressure pump, and a filter. The integral filter housing is mounted at the pressure pump outlet. The scavenge pumps are oversized to provide breathing capability through the oil scavenge system.

The forward bearing compartment for the STJ346A, shown in figure 13, incorporates one set of ball bearings with a stationary support. The front end of the compartment is enclosed so that sealing is necessary only at the rear. This significantly reduces heat generation in the compartment. Bleed air provides pressurization of the remaining seal. Passages are provided to allow the oil, supplied by the jet at a rate of about 30 lb/min, to cool and lubricate the bearing, lubricate the bevel gear connection with the tower shaft, cool the seal face, and cool and lubricate the tower shaft bearings. The compartment is completely insulated to reduce the heat transfer from surrounding environments. Scavenging and breathing is accomplished through the tower shaft to the gearbox.

The gearbox configuration, shown in figure 15, is designed to have the capabilities of transmitting 52,800 in.-lb at 7500 rpm to the PTO shaft, 100 in.-lb at 4000 rpm to the oil pump package, and 5650 in.-lb at 7500 rpm to the main fuel pump. Power transmission is accomplished through 5 gearshafts and 10 bearings. The breather system deoiler is located inside the gearbox. The gearbox housing would be insulated to reduce environmental heating.

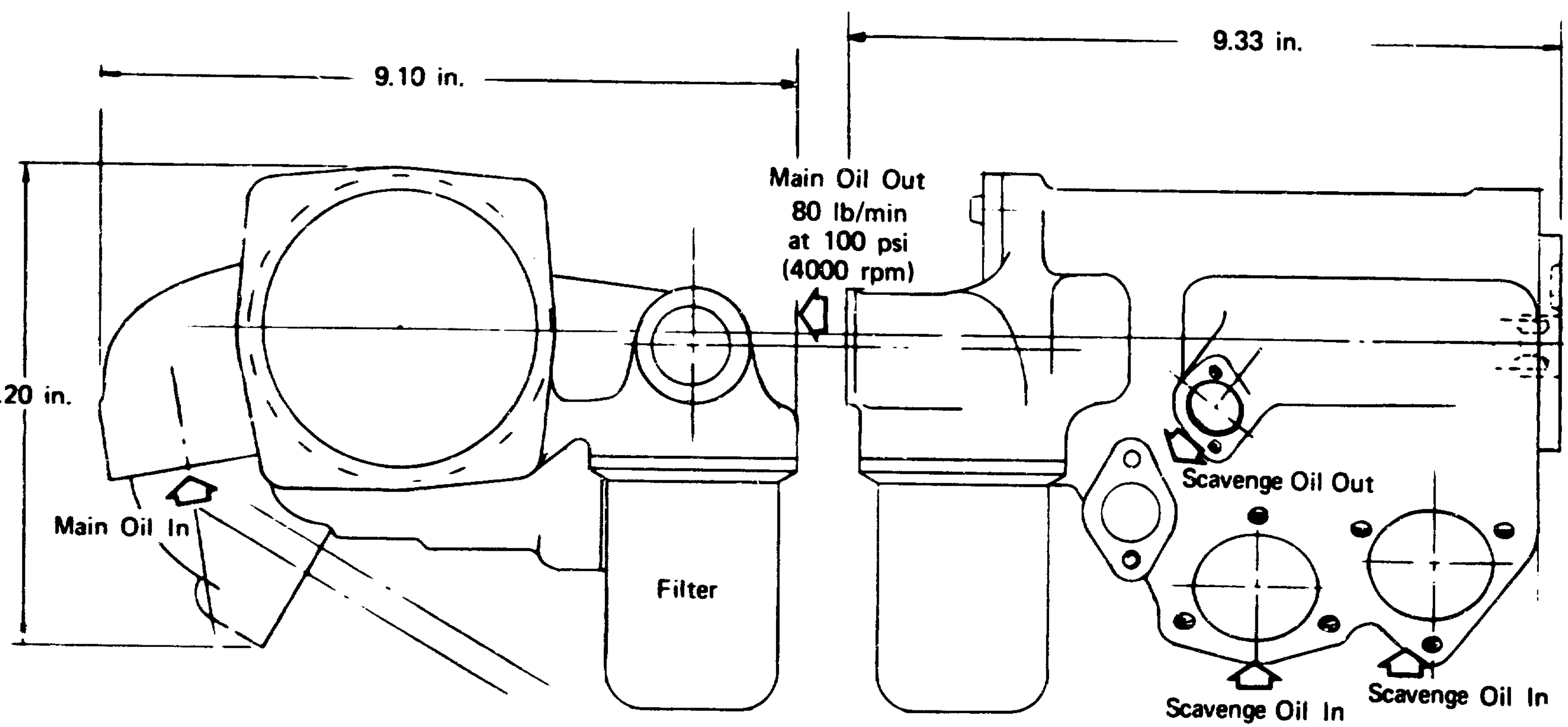


Figure 17. STJ346A Oil Pumps and Filter

The rear bearing compartment configuration, shown in figure 14, features a single oil-damped roller bearing. Oil is fed directly to the bearing seat to provide the dampening. Oil from the jet is supplied at a rate of about 30 lb/min to the bearing for lubricating and cooling purposes and to the seal face for cooling. There is only one seal needed since the aft end of the compartment is enclosed for reduction of heat generation. Compressor bleed air is used to pressurize the seal. The compartment is completely insulated to reduce heat transfer from the outside. The oil scavenge was placed at the bottom of the compartment. Breathing is accomplished through the oil scavenge line.

Performance data for lubrication system components are contained in Appendix II.

D. STJ346A FUEL AND LUBRICANT TEMPERATURES

The primary constraint in the use of the candidate fuels and lubricants in the STJ346A engine is the operating temperature of the fluids in comparison to their thermal stability temperature limits. Accordingly, a primary goal was to determine maximum fuel and lubrication system temperatures, requiring the evaluation of many operating conditions and alternate design concepts. To do this efficiently required the development of a computer model of the system to calculate fuel and lubricant temperatures. Appendix I describes this program and contains examples of computed data tabulations.

Many operating conditions were evaluated to assess the most severe fluid temperature conditions that might be encountered. These included (1) temperature profiles for the baseline mission, (2) component temperature profiles for the most severe mission point and for alternate interface temperatures, (3) localized lubricant hot spot temperatures, (4) maneuvers with transiently low fuel flow, and (5) flight envelope operating point extremes.

1. Baseline Mission Temperature Profiles

Fuel and lubricant stream temperature profiles were computed for the STJ346A engine. The computer program, following the computational routine illustrated in figure 18, provided a rapid calculation of the STJ346A afterburning turbojet fuel and lubrication system temperatures at selected points during the mission. Thirty-nine flight conditions were analyzed to cover the range of speeds and altitudes included in the mission and shown on figures 19 and 20. For each of the 39 points, the computer printed out calculation results for the baseline system.

Computer printout examples for plotted data points are included in Appendix I. Output nomenclature, examples of computer program data plots, and tabulated output are shown. Component performance and thermal characteristics that were input to the computer program for calculation of the fuel and lubricant temperatures are listed in Appendix II.

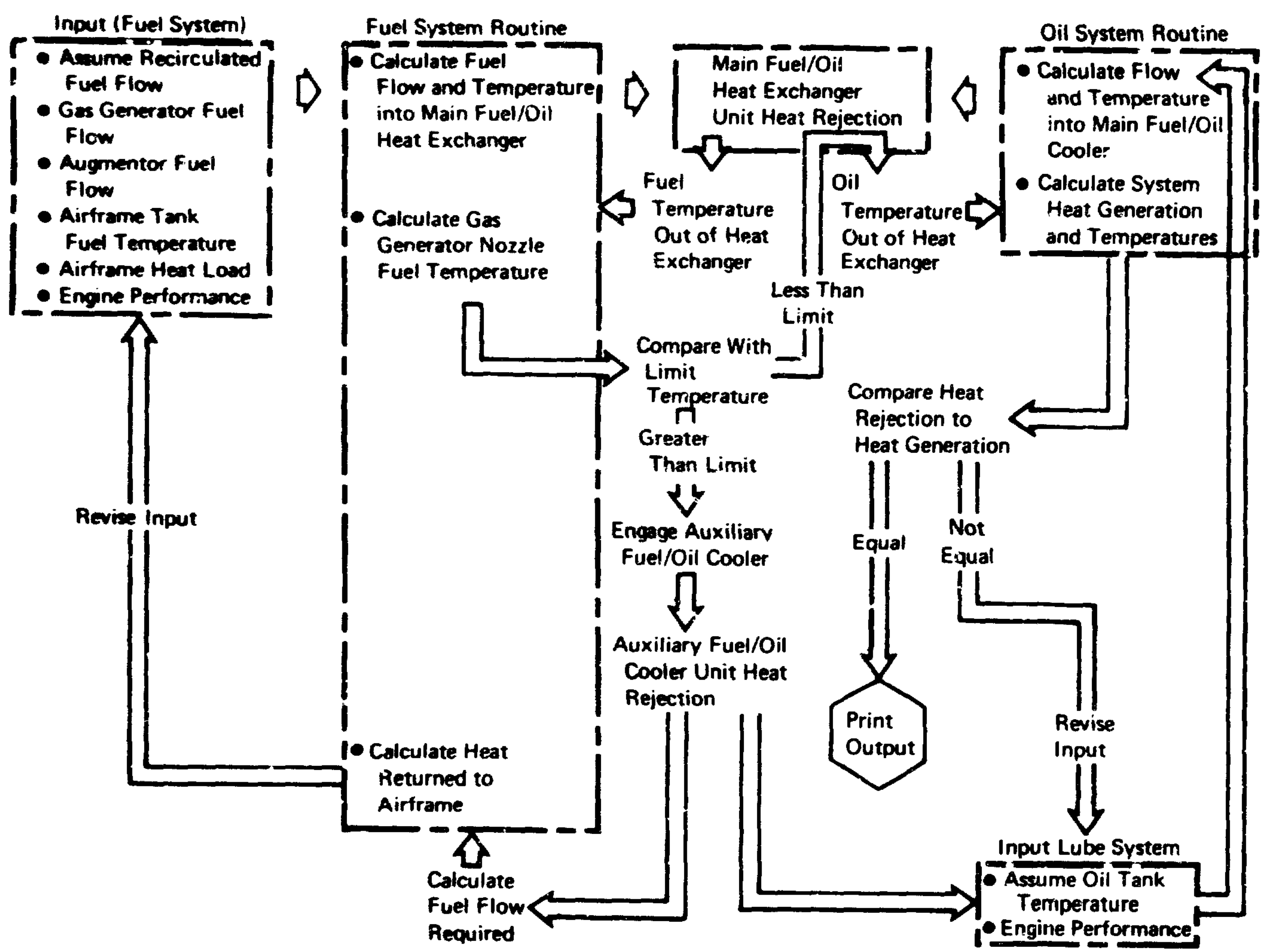


Figure 18. STJ346A Engine Thermal Analysis Flow Chart

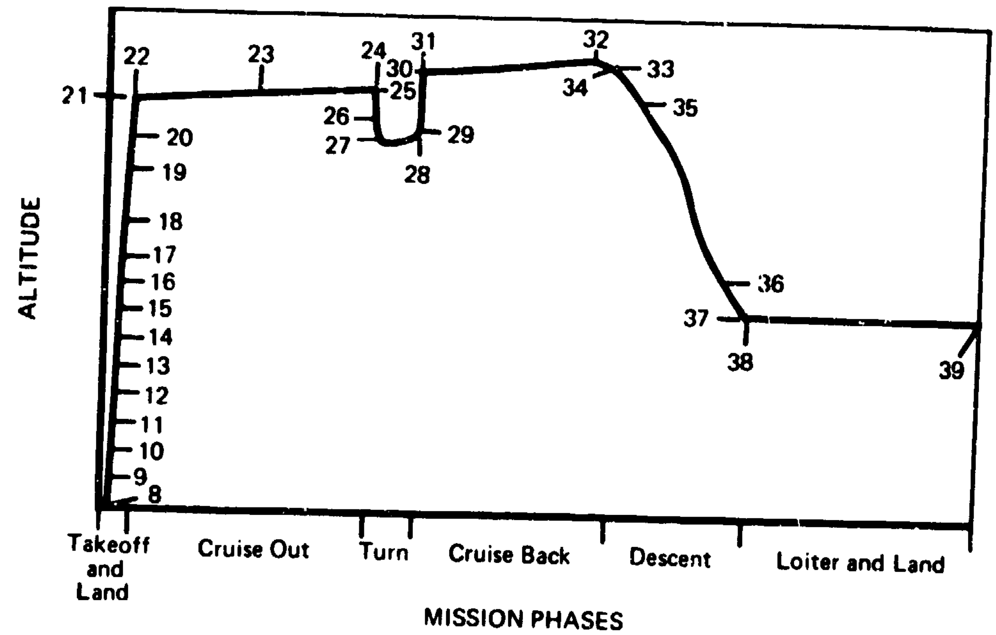


Figure 19. STJ346A Computer Program Mission Altitude Coverage

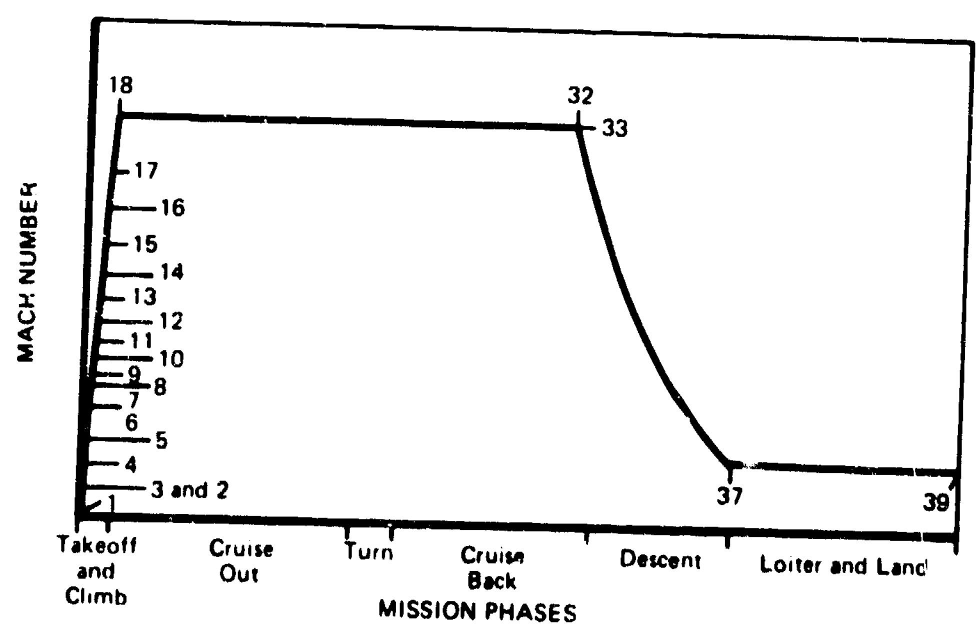


Figure 20. STJ346A Computer Program Mission Mn Coverage

A plot of fuel temperature vs mission time at the airframe tank, engine inlet, gas generator nozzles, and afterburner nozzles is shown in figure 21. The fuel tank temperature is based on rates of temperature change and airframe fuel system management information obtained from McDonnell Douglas. During cruise operation, fuel flow to each engine cools an airframe heat load of 6700 Btu/min. For the descent after cruise back, fuel is circulated through an airframe system heat exchanger for cooling of aircraft loads, including avionics and aerodynamic heat, as controlled by the aircraft thermal management system. Since this relieves the cooling load on the engine fuel flow, the aircraft/engine interface temperature is reduced significantly. However, the heat added to the aircraft fuel tank causes a rapid increase in the fuel tank temperature, figure 21, during descent. During cruise, the aircraft heat load accounts for approximately 3/4 of the total fuel temperature rise.

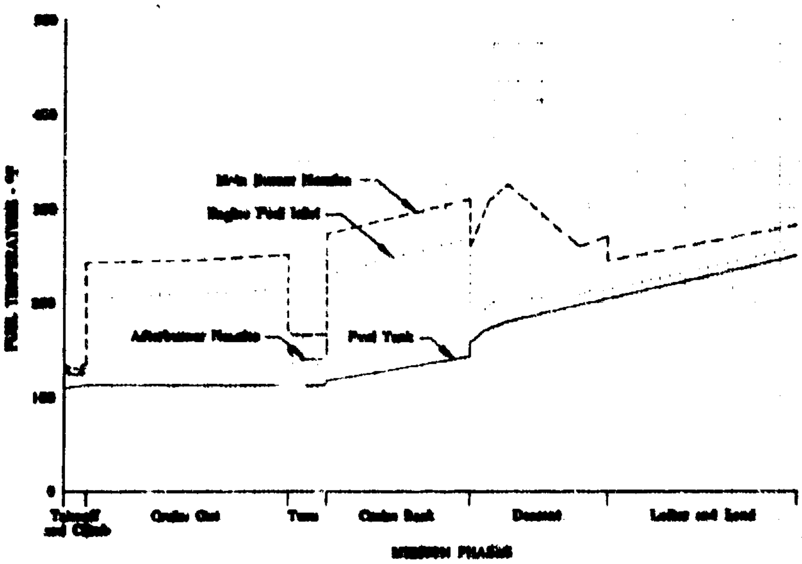


Figure 21. STJ346A Mission Fuel Temperatures

The lubricant temperatures at the oil tank, at oil cooler exit, out of the front and rear bearing compartments, and out of the main gearbox, are shown for the mission phases in figures 22 and 23. These temperature profiles illustrate that steady-state lubrication system temperatures follow the trends of the fuel system and show relatively low temperatures due to relatively cool fuel into the oil cooler. Figures 24 and 25 show lubricant flow and heat rates, respectively.

The engine fuel flowrates, inlet temperatures, and fuel temperature limit determine the maximum potential heat sink of the fuel consumed by the engine. The high fuel flowrates and low heat generation during the majority of the mission resulted in low fuel temperatures at the fuel nozzles. The percentage utilization of the heat sink available from fuel that is consumed by the engine was computed at each flight condition as shown in figure 26 for JP-7. Since generally less than 25% of the available sink was used, other ways to use the excess cooling capability

or to use fuel of lesser capabilities were considered. However, it was also necessary to evaluate conditions other than the baseline mission that might entail higher operating temperatures.

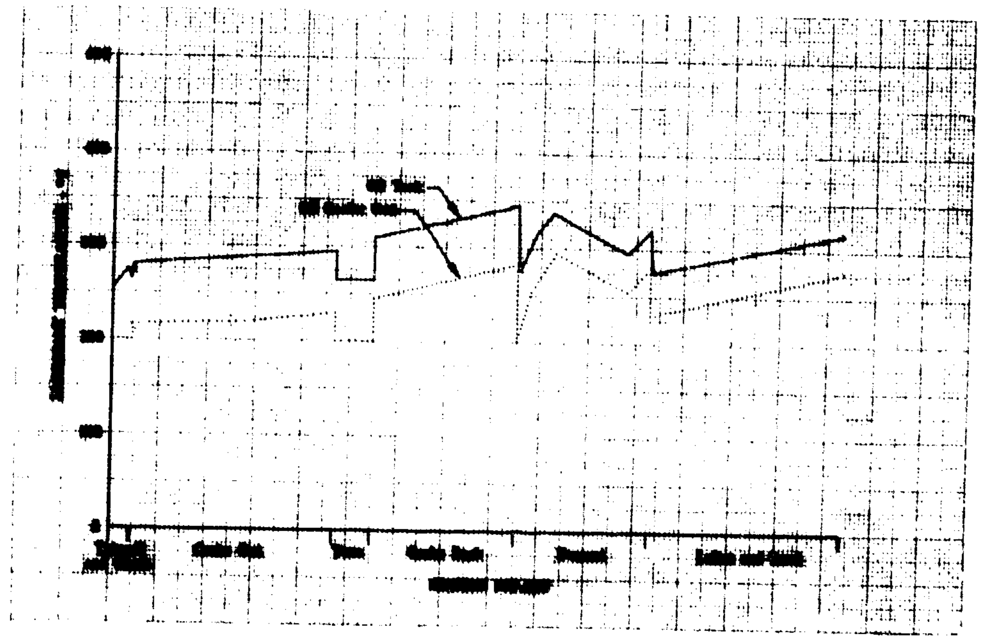


Figure 22. STJ346A Mission Lubricant Temperatures

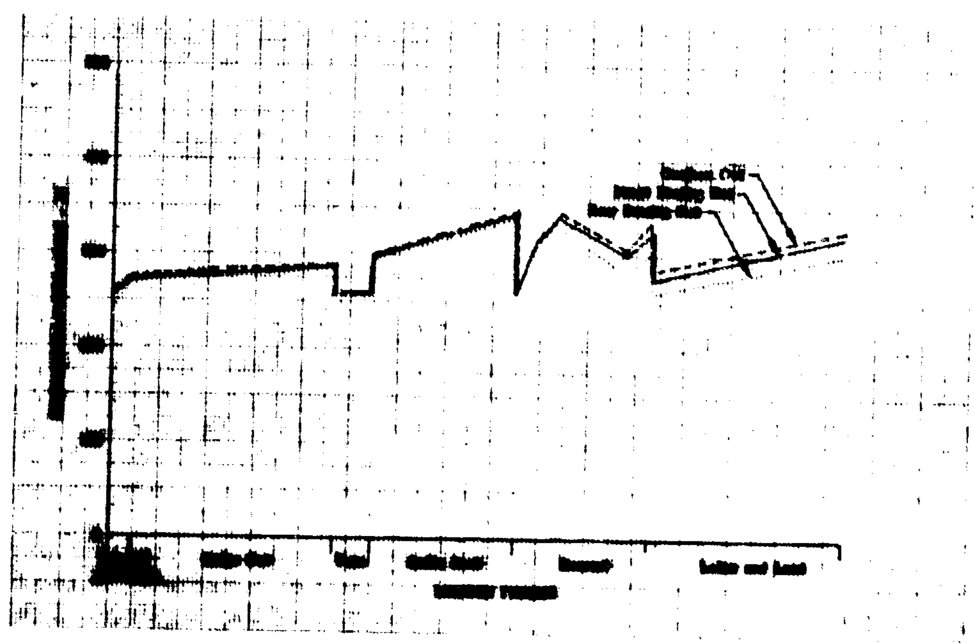


Figure 23. STJ346A Mission Lubricant Temperatures

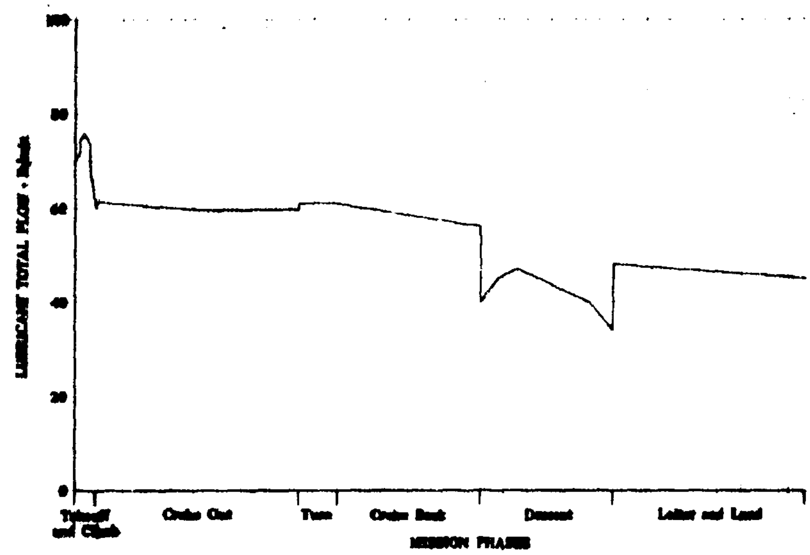


Figure 24. STJ346A Mission Lubricant Total Flow

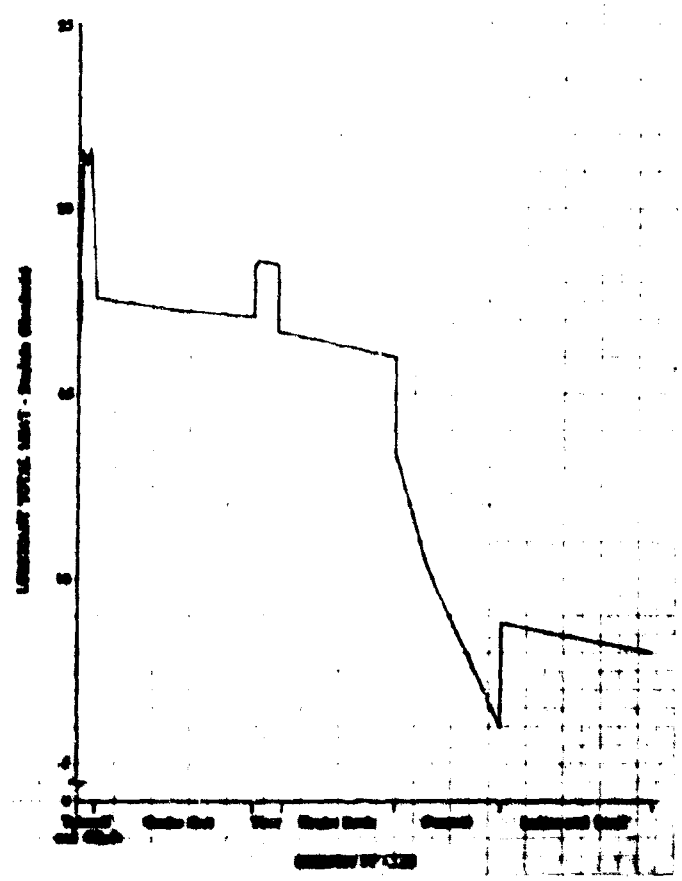


Figure 25. STJ346A Mission Lubricant Total Heat

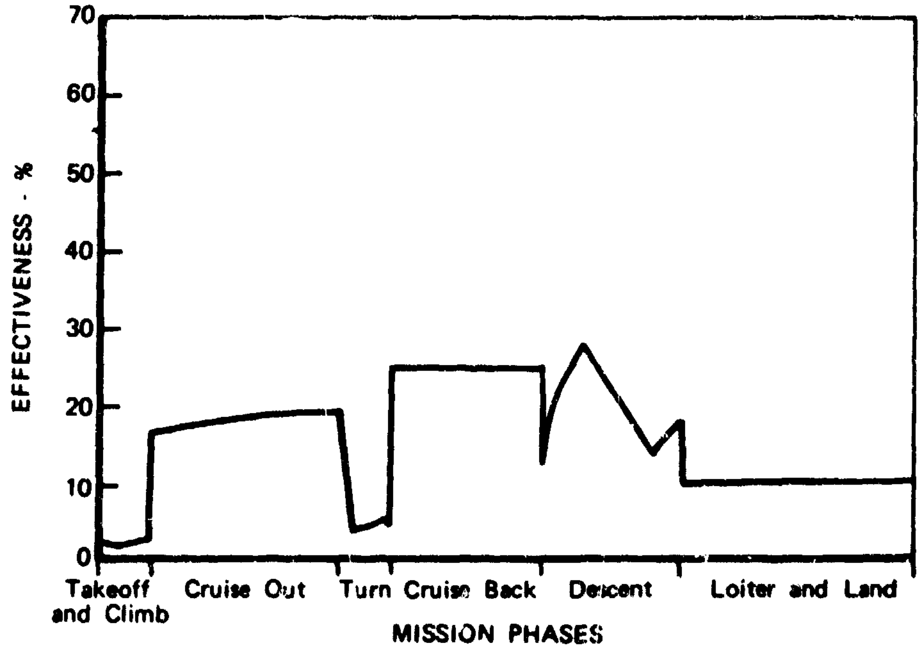


Figure 26. STJ346A Utilization of Potential Fuel Heat Sink

2. STJ346A Component Temperature Profiles

The fuel and lubricant temperature profiles shown in the prior section were based on one prescribed mission, aircraft tank temperature profile and particular aircraft heat load (6700 Btu/min/engine). Maximum fuel temperature was 325°F and maximum lubricant temperature was 345°F. Higher tank temperatures and/or aircraft heat loads would have resulted in higher system temperatures. Figure 27 shows the component fuel temperatures that occur during Mach 3+ cruise for alternate aircraft heat loads that result in aircraft/engine interface temperatures (gas generator pump inlet) of 150, 250, and 350°F. The temperature rise from the pump to fuel nozzles of the gas generator varied from more than 100°F for 150°F interface temperature to less than 50°F for 350°F interface temperature, as a result of reduced environmental heating and increased specific heat of the fuel as temperature level increased. Although heat loads are substantial, relatively high fuel flows at high Mach, steady-state flight conditions limit maximum fuel temperatures during cruise.

Figure 28 shows the corresponding bulk lubricant temperature profile for 150, 250, and 350°F interface fuel temperatures. Temperature is plotted for each component at the cruise flight condition. Much higher temperatures can occur at local hot surfaces in the engine wetted by lubricant, but proper design can alleviate the severity of this potential problem as shown in the next section.

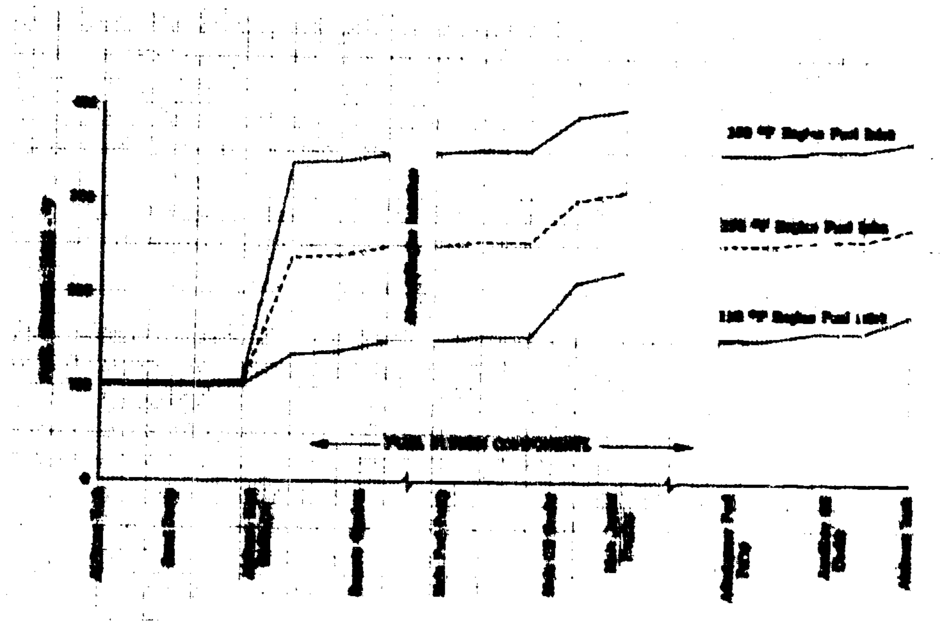


Figure 27. STJ346A Fuel Stream Temperature Profile for Cruise Thrust Requirements

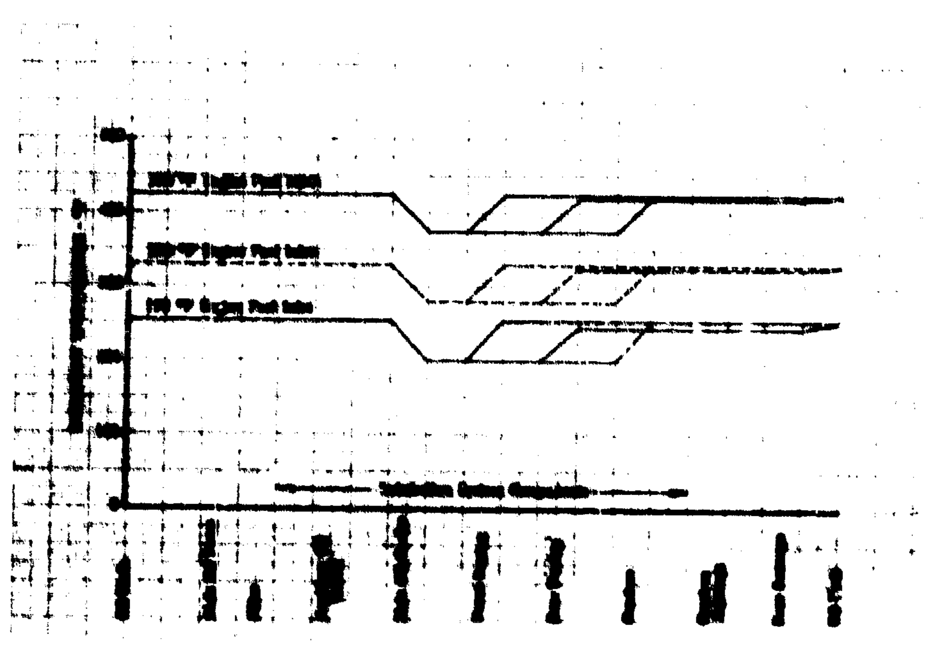


Figure 28. STJ346A Lubricant Stream Temperature Profile for Cruise Thrust Requirements

3. Lubricant Hot Spots

Thermal analysis of the initial baseline fuel and lubrication system led to revised distribution of lubricant to equalize lubricant temperature. Bulk lubricant temperatures were relatively low, reflecting the relatively low fuel temperature available for cooling; however, bearing compartment environmental temperature of 1500°F provided the potential for the coking of lubricant on hot compartment walls. This potential problem was investigated, and corrective designs were developed as outlined in the following paragraphs. None of the modifications had significant weight or performance influences on the STJ346A engine.

The bearing compartments and gearbox of the STJ346A engine were analyzed for locally high metal temperatures (hot spots) that could be contacted by the lubricant. The analysis of hot spots required the use of an in-house general purpose heat transfer computer deck (PWA™ FTDM-454) to compute temperature distributions in the bearing compartments and gearbox. In this computer program, the component can be divided into a network of up to 200 elements, and iterative heat balances can be calculated for each element or node. Up to six conduction, four convection, four radiation between nodes, four radiation to other surfaces, and internal heat generation heat transfer terms can be applied to each node.

For computer analysis of temperatures in the front bearing compartment, the component was divided into 81 elements or nodes, numbered for identification as shown in figure 29. The rear compartment was divided into 58 nodes for similar thermal analysis. Lubricant flowrates, bulk oil temperatures (BOT), and maximum computed metal temperatures (hot spots) are shown in table I for the initial thermal analysis. The analysis was based on mission points where maximum bulk oil temperatures occurred. The hot spot temperatures indicated the need for modifications to minimize the tendency for lubricant coking.

The hot spots in the front bearing compartment resulted from a conical support web and a knife edge seal land that conducted heat into the shielded bearing compartment through attachment flanges at the bearing and seal supports. These hot spots are indicated by the circled points in figure 29. The design was improved by revising the knife edge seal land flange to add insulation around the bearing seal and by shielding the compartment support web. (See figure 30.)

The hot spots in the rear bearing compartment, shown by circled points in figure 31, resulted from seal pressurizing air heating seal support rings that were exposed to lubricant splash. A part of the shaft (rearward of the insulated plug) was also subjected to heating by seal-pressurizing air. The compartment mount flange provided a direct heat path to an oil-wetted wall. The design was improved by enclosing the seal to shield hot-gas-pressurized surfaces from lubricant splash, rearward movement of the insulated shaft plug, and shielding of the compartment mount flange (figure 32).

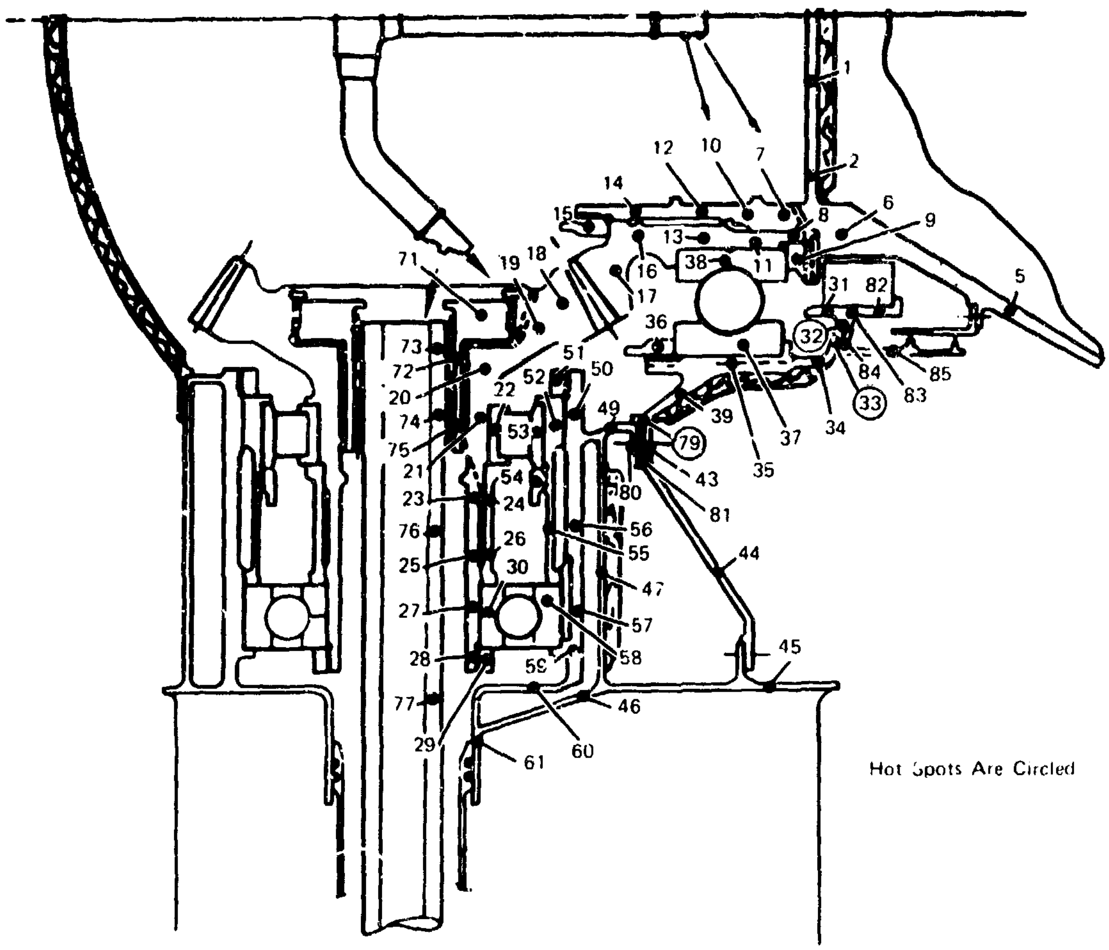


Figure 29. Original STJ346A Front Bearing Compartment Temperature Analysis Points

Table I. STJ346A Hot Spots for Original Design

	Front Bearing Compartment		Rear Bearing Compartment		Gearbox	
Mission Point No.*	1	32	1	32	1	32
Oil Flow, lb/min	39.9	32.2	20.3	16.4	9.8	7.9
Bulk Oil In, °F	200	294	200	295	200	294
Bulk Oil Out, °F	257	344	243	346	259	347
Baseline Hot Spot, °F	467	670	949	845	253	467
Location	Tower Shaft Gear	Seal Support Flange	Seal Carrier Ring	Seal Carrier Ring	Side-wall	Drive Pad

*Mission points 1 and 32 are at sea level takeoff and at the end of the cruise back.

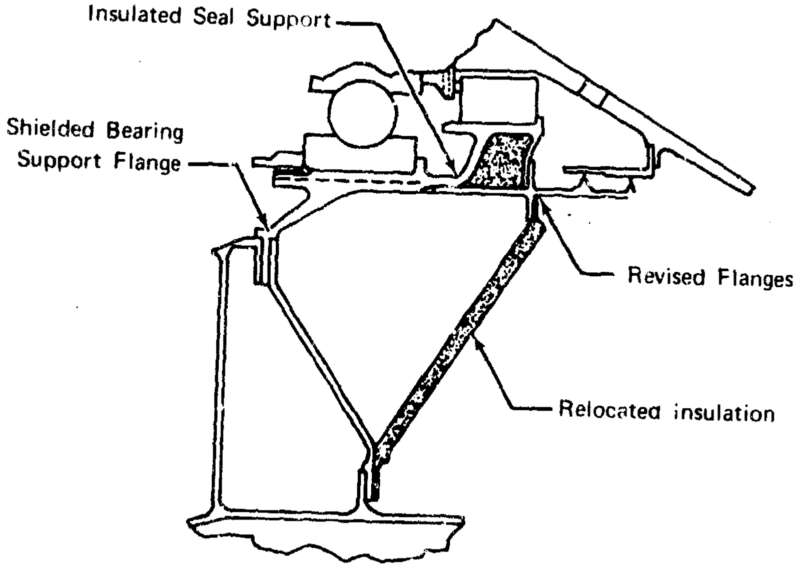


Figure 30. Revisions of STJ346A Front Bearing and Seal Supports

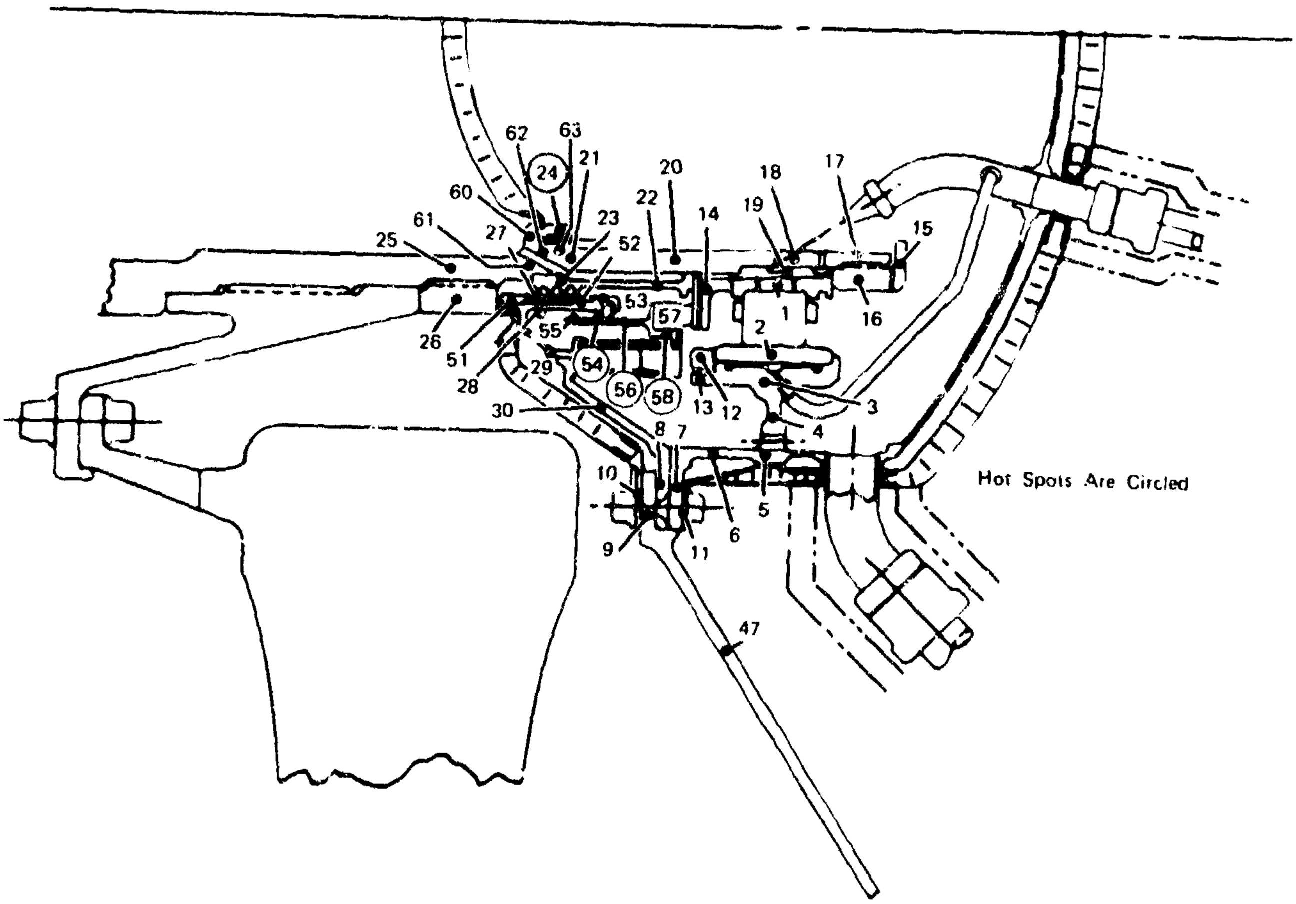


Figure 31. Original STJ346A Rear Bearing Compartment Temperature Analysis Points

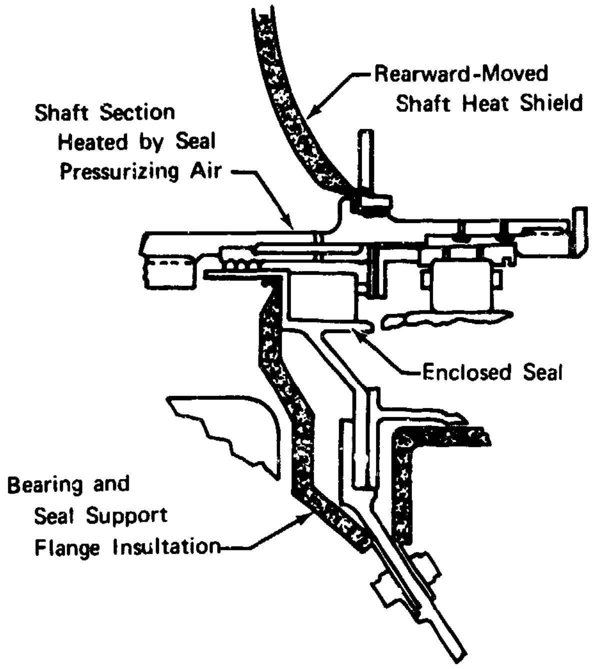


Figure 32. Revisions of STJ346A Rear Bearing and Seal Supports

Evaluation of the above modifications included the bulk oil-out temperatures for each bearing compartment and the gearbox, shown for each phase of the mission in figure 33. The maximum bulk oil temperature of 347°F occurred at the gearbox discharge at the end of the cruise back. Temperatures for localized areas of the bearing compartments and gearbox were calculated for sea level takeoff and the end of the cruise back. Sea level takeoff was selected because the high engine operating pressures maximized seal heat loads and the end of the cruise back gave the highest bulk oil temperatures in conjunction with the Mach 3+ environmental temperatures. The continuous altitude increase, assumed in the baseline mission to minimize fuel consumption during cruise, resulted in the lowest fuel flow available for cooling and the correspondingly highest bulk oil temperature at the end of the cruise. The engine fuel inlet temperature increased later in the mission, but it was offset by reduced environmental and engine heat loads. Bulk oil temperatures used in the analysis of the compartments hot spots are shown for each selected mission point by temperature profiles in figure 34.

The STJ346A reduced hot spot temperatures for the revised configuration are summarized in table II. In the baseline design, the maximum oil-wetted surface temperature was 949°F on the rear bearing compartment face seal carrier ring at sea level takeoff. In the revised designs, the maximum wetted surface temperature was reduced 399°F (to 550°F) on the rear bearing compartment seal support flange at the end of the cruise back.

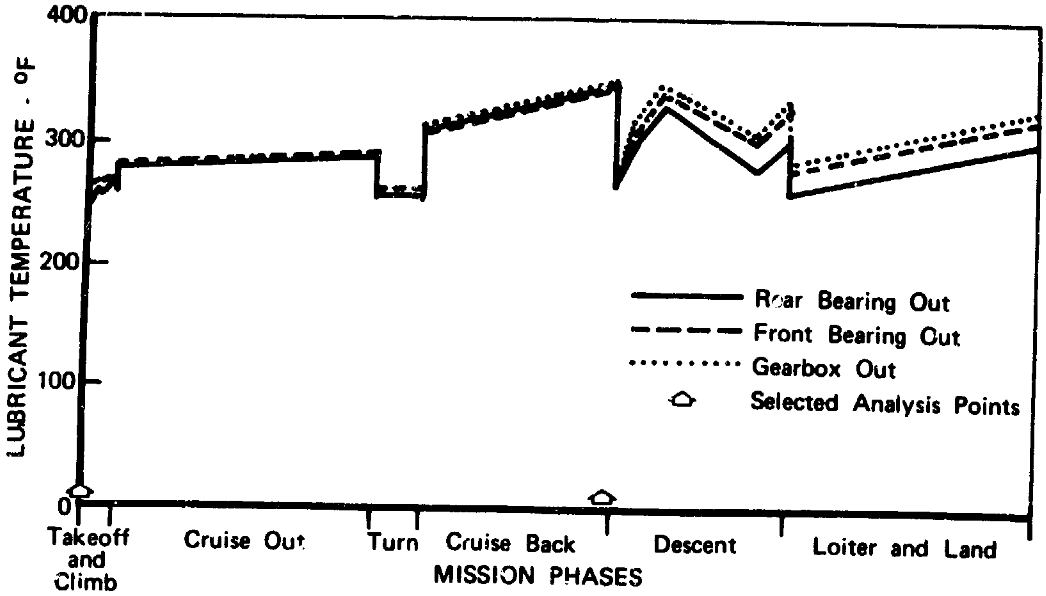


Figure 33. STJ346A Bearing Compartment and Gearbox Lubricant Temperatures During the Mission

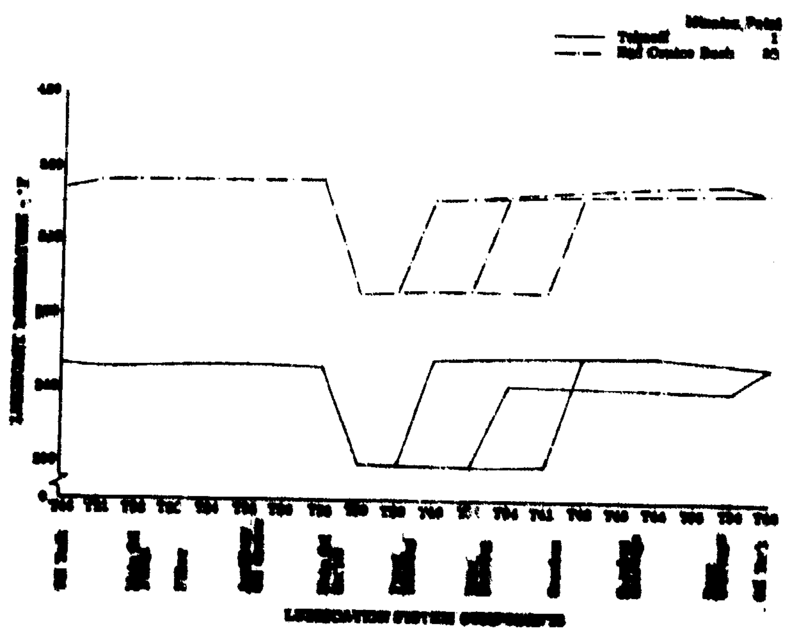


Figure 34. STJ346A Lubricant Stream Temperature Profiles for Sea Level Takeoff and the End of Cruise

Table II. Hot Spots for Revised Design

	Front Bearing Compartment		Rear Bearing Compartment		Gearbox
Maximum Temperature, °F	469	529	447	550	No Changes
Location	Tower Shaft Gear	Tower Shaft Gear	Seal Plate	Seal Support Flange	No Changes
Hot Spot Reduction, °F	0	141	502	295	

The lubricant stream temperature profiles (figure 34) showed a maximum bulk oil temperature of 355°F at the inlet to the main oil cooler at the end of the cruise which would indicate no lubricant thermal problems. However, the hot spot thermal analysis showed that lubricant could contact a surface whose temperature was 949°F at sea level takeoff, which would exceed thermal stability limits of all of the candidate lubricants. Configuration changes reduced the maximum lubricant contact temperature to 550°F at the end of the cruise back, which should be compatible with the use of common lubricants.

The front bearing compartment maximum temperatures were also calculated to occur at the end of the cruise back. The hot spots at the seal support and the bearing support mount flange (circled nodes in figure 29) were 670°F and 540°F. These hot spots were reduced 232°F and 45°F by revising the flanges, insulating the seal support, and by relocating insulation for the bearing support flange, as shown in figure 30. The calculated temperatures for each component node in the revised STJ346A front bearing compartment, figure 35, are provided in table III. This table shows that the maximum lubricant-wetted surface temperature was reduced to 529°F at the tower shaft gear (node point No. 18). This maximum front bearing, compartment-wetted surface temperature occurred at the end of the cruise back.

The hot spot analysis for the original STJ346A rear bearing compartment (figure 31) showed high temperatures on lubricant-wetted surfaces that were heated by seal pressurizing air. These extremes occurred at the encircled nodes in figure 31. Other high temperature locations were the bearing support flange and a section of the shaft that was aft of the insulated plug and heated by the seal pressurizing air. The calculated temperatures were generally highest at the end of the cruise, where the highest bulk oil temperature coincided with the Mach 3+ environmental conditions; however, the highest lubricant-wetted surface temperature occurred at the face-seal-carrier-ring at sea level takeoff, because the high engine power setting and sea level pressure level were more influential than high environment and oil temperature at the end of the cruise back. The hottest spots were eliminated by insulating, relocating seal supports and using a bellows mounting concept to enclose seals that should prevent lubricant splash on the hot-gas-pressurized surfaces. The other surface area temperatures were reduced (figure 36) by moving the insulated shaft plug aft to prevent lubricant contact on the section of the shaft heated by seal-pressurizing air and by enclosing the bearing support flange with insulation. The calculated temperatures for each of the component nodes in the revised STJ346A rear bearing compartment (figure 36) are provided in table IV. This table shows that the maximum lubricant-wetted surface temperature was reduced to 550°F at the seal support mount flange. This maximum temperature occurred at the end of the cruise back.

Wall temperatures were analyzed for the STJ346A gearbox for the typical locations shown in figure 37. These localized points ranged from insulated wall areas to accessory mount flanges. Calculated temperatures in table V show that the insulated wall areas approached the lubricant discharge temperature under low ambient temperature conditions, such as sea level takeoff. At high ambient conditions, such as the Mach 3+ cruise, the accessory mount pads showed the highest calculated temperatures. In either case, the maximum calculated temperature on a lubricant-wetted gearbox surface did not exceed 467°F, and no configuration revisions were necessary.

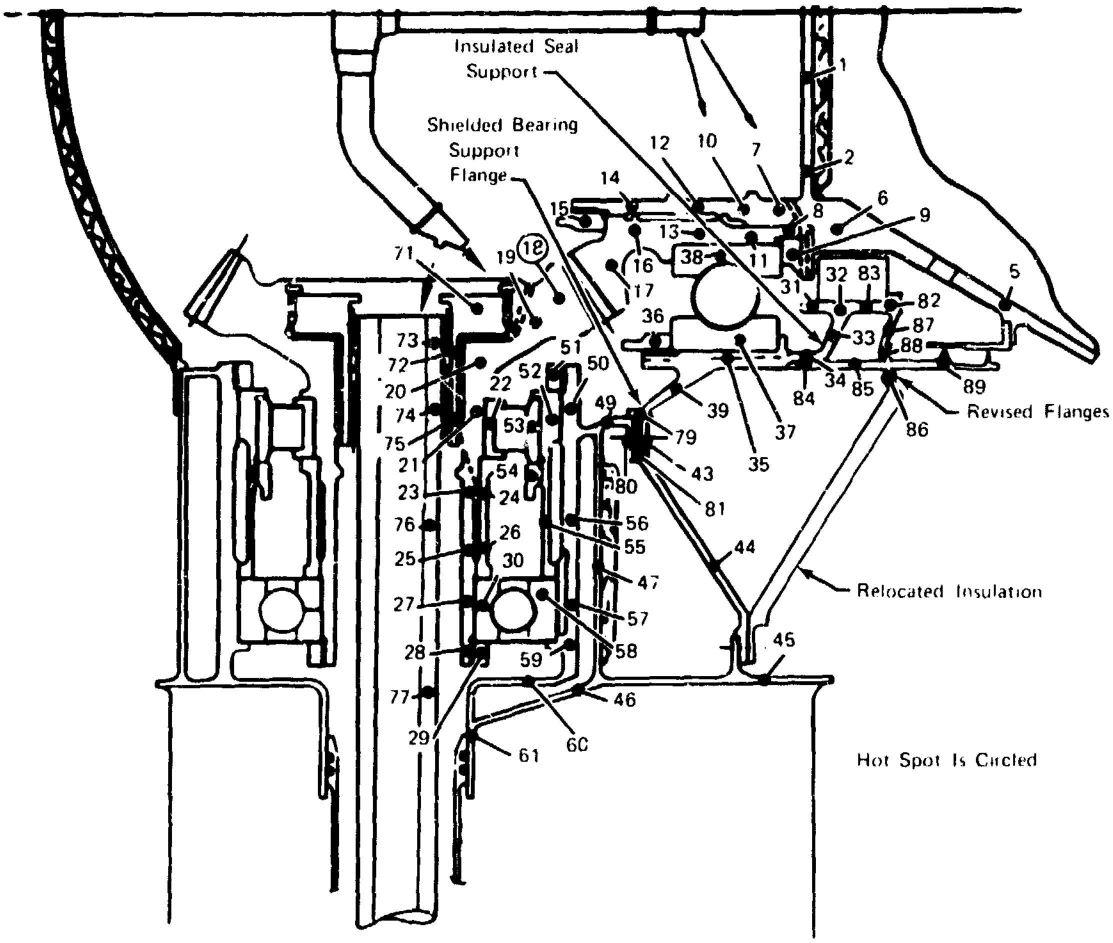


Figure 35. STJ346A Front Bearing and Seal Support Revisions and Temperature Analysis Points

The trend for higher lubricant temperature leads to concern for allowable gear loading to prevent failures due to abrasion and scoring. A literature search revealed no proved procedure for design of gears, based on the influence of lubricant characteristics on allowable gear loading. The elastohydrodynamics (EHD) theory has proved useful in estimating film thickness in bearing lubrication and appears to offer potential for analysis of allowable gear loading. Accordingly, analytical and experimental work is recommended to develop design systems for gears that include the influence of lubricant characteristics on allowable gear

loading. This could eliminate potential failures due to operation at higher lubricant temperatures than previously experienced and produce significant weight savings in other applications such as geared fans, helicopter reduction gears, and turboprops.

Table III. STJ346A Revised Front Bearing Compartment Calculated Temperatures

Mission Point		1	32		1	32
	Node	Temperature, °F	Temperature, °F	Node	Temperature, °F	Temperature, °F
	1*	241	359	43	454	604
	2*	242	357	44	280	735
	5	721	1326	45	67	851
	6	492	719	46*	206	432
	7*	245	345	47*	232	362
	8*	255	343	49*	235	330
	9*	285	368	50*	248	334
	10*	234	324	51*	245	332
	11*	263	346	52*	253	338
	12*	255	340	53*	259	343
	13*	289	367	54*	235	324
	14*	297	377	55*	234	323
	15*	288	389	56*	246	328
	16*	312	389	57*	293	349
	17*	378	448	58*	341	370
	18*	469	529	59*	269	337
	19*	389	458	60*	239	324
	20*	312	390	61*	229	326
	21*	279	361	71*	205	385
	22*	285	366	72*	240	329
	23*	243	329	73*	240	328
	24*	243	329	74*	233	323
	25*	258	333	75*	233	323
	26*	255	331	76*	229	319
	27*	346	372	77*	228	319
	28*	325	362	79*	361	495
	29*	325	363	80	431	575
	30*	367	382	81	440	586
	31*	276	407	82	539	830
	32	339	516	83	437	669
	33*	289	438	84	333	540
	34*	315	502	85	513	868
	35*	259	367	86	675	1140
	36*	244	341	87	631	999
	37*	260	362	88	665	1105
	38*	309	383	89	734	1376
	39*	275	402			

*Lubricant-wetted surfaces

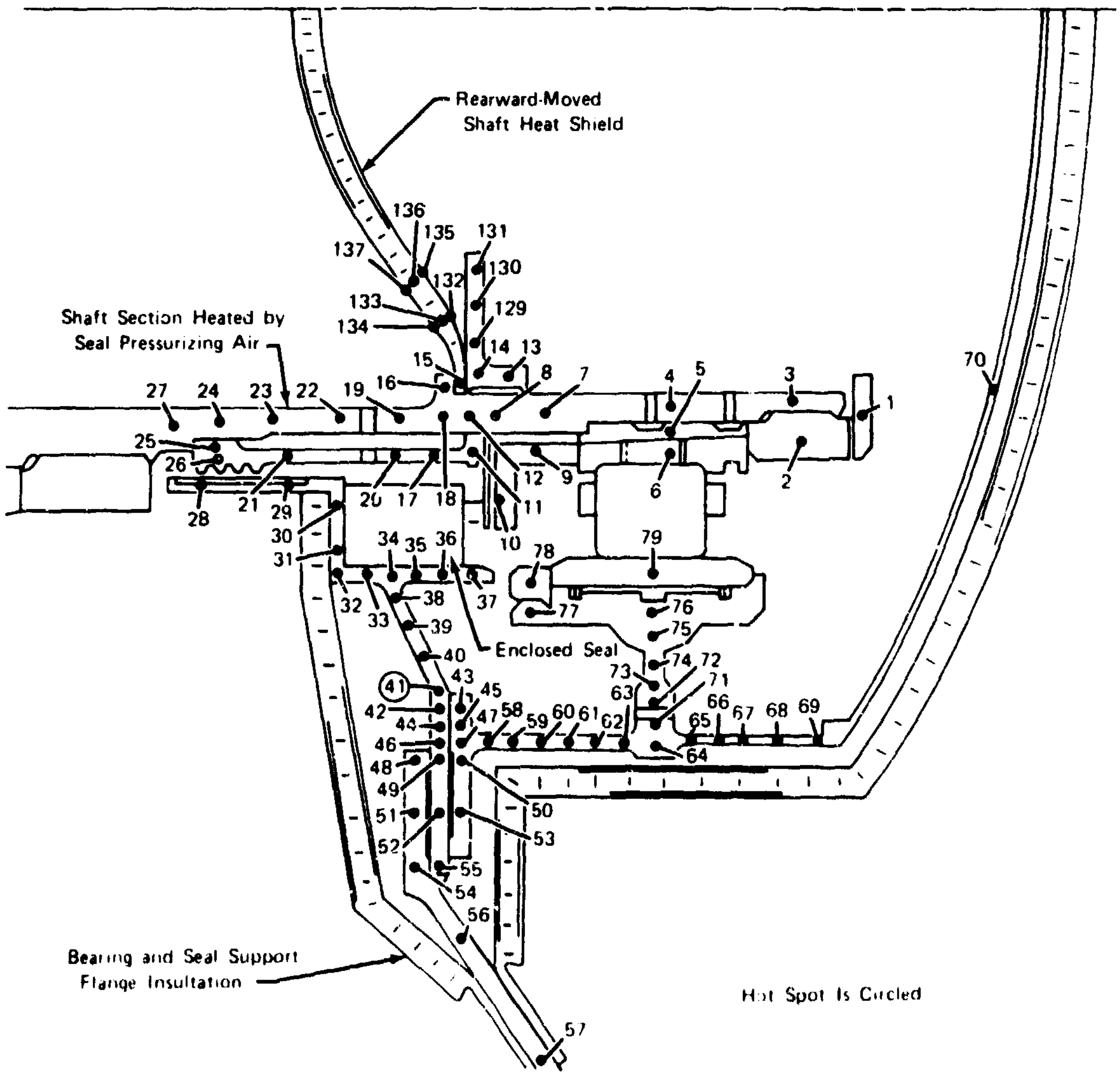


Figure 36. STJ346A Rear Bearing and Seal Revisions and Temperature Analysis Points

Table IV. STJ346A Revised Rear Bearing Compartment Calculated Temperatures

Mission Point		1	32		1	32
	Node	Temperature, °F	Temperature, °F	Node	Temperature, °F	Temperature, °F
	1*	230	330	45*	284	511
	2*	233	332	46	372	734
	3*	228	328	47	285	512
	4*	239	340	48	435	887
	5*	296	395	49	389	777
	6*	315	415	50	295	538
	7*	259	365	51	473	974
	8*	290	420	52	412	827
	9*	324	419	53	328	624
	10*	447	473	54	499	1026
	11	420	541	55	454	925
	12	330	494	56	576	1180
	13*	280	416	57	727	1438
	14	294	445	58*	267	462
	15	310	479	59*	254	426
	16	325	505	60*	245	401
	17	498	645	61*	239	383
	18	350	546	62*	235	370
	19	435	742	63*	232	359
	20	579	869	64	229	350
	21	712	1202	65*	229	352
	22	508	912	66*	230	355
	23	536	977	67*	230	356
	24	736	1388	68*	230	358
	25	735	1370	69*	232	364
	26	735	1367	70*	230	354
	27	738	1407	71*	227	343
	28	733	1332	72*	225	338
	29	704	1226	73*	225	335
	30	606	1036	74*	223	330
	31	511	883	75*	223	325
	32	434	750	76*	223	324
	33	373	640	77*	221	322
	34	323	548	78*	221	321
	35*	292	485	79*	295	439
	36*	268	431	129*	263	395
	37*	247	385	130*	246	366
	38*	301	516	131*	232	341
	39*	286	497	132*	250	378
	40*	286	510	133	326	526
	41*	299	550	134	406	679
	42	320	606	135*	232	348
	43*	289	524	136	357	589
	44	348	677	137	479	926

*Lubricant-wetted surfaces

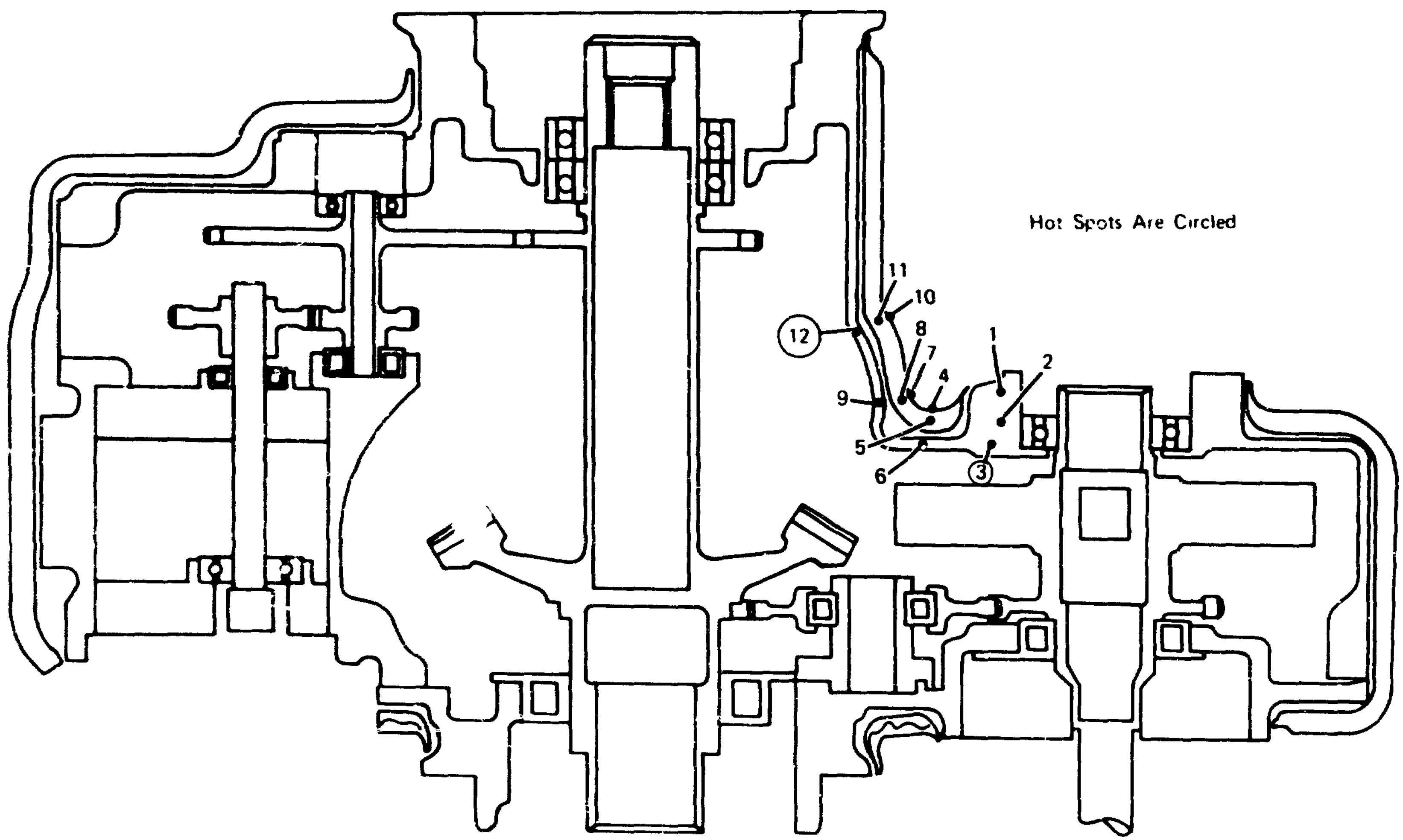


Figure 37. STJ346A Gearbox Temperature Analysis Points

Table V. STJ346A Gearbox Wall Calculated Temperatures

Mission Point	1	32	
Node	Temperature, °F	Temperature, °F	
1	207	485	
2	208	482	
3*	214	467	
4	66	852	
5	154	640	Wall temperatures are typical for other locations of similar geometry.
6*	241	401	
7	98	735	
8	175	567	
9*	251	373	
10	99	732	
11	176	561	
12*	253	366	

*Lubricant-wetted surfaces

4. Recirculation to Reduce Transient Temperatures

a. Baseline STJ346A Temperature Effects

The preceding fuel and lubricant temperatures were calculated for steady-state flight conditions; however, the STJ346A engine must function satisfactorily over broader extremes including transients. The fuel cooling ability will be the least at minimum engine power settings (low fuel flow), causing fuel and lubricant temperatures to be the highest. Lowest fuel flows occur at steady-state flight conditions of high altitude and minimum flight speed and at transient maneuver conditions when engine power is reduced to idle. The highest fuel temperatures will occur for the transient condition when power is reduced to idle at maximum cruise Mach number because heat loads will be the highest and will remain high for a finite time after fuel flow has been reduced. The maximum temperature increase that can be calculated would be to assume idle fuel flow combined with cruise heat loads, causing the increase in system temperatures from the cruise profile to the "throttle-chop" profile shown in figure 38. These profiles show the progressive increase in fuel temperature as the fuel passes through each component until it reaches the maximum temperature just before combustion in the main burner. The largest temperature rise is shown to occur across the airframe heat exchanger; this may be reduced by increasing fuel flow and recirculating the excess flow back to the aircraft tanks (the baseline design includes 1000 lb/hr minimum recirculation). The effectiveness of this fuel recirculation technique in reducing maximum fuel temperatures is illustrated in figure 39.

A 6700 Btu/min/engine aircraft heat load has been estimated to be representative for a twin engine Mach 3+ class interceptor using hot structure, including heat loads due to aerodynamic heating and environmental control systems, avionics, and hydraulics. For this heat load, figure 39 shows that for a particular fuel temperature in the tank, increasing recirculation rate of fuel from 0 to 4000 lb/hr will reduce the maximum fuel temperature nearly 200°F. This would reduce the maximum transient temperature, at reduction of STJ346A engine power to idle, to the approximate level of steady-state cruise fuel temperature. There

would be no advantage to reduce temperature further by increased fuel recirculation, since the excess heat is returned to aircraft tanks and not disposed. Fuel temperature in the aircraft tank would increase, postponing the problem, and recirculation can, therefore, only be used as a solution to transient overtemperature. Figure 39 also shows the increase in burner nozzle fuel temperature resulting from an increase in aircraft tank fuel temperature. At a recirculation rate of 4000 lb/hr, aircraft tank fuel temperatures up to 300°F would be compatible with a fuel having the capability for use at temperatures up to 500°F.

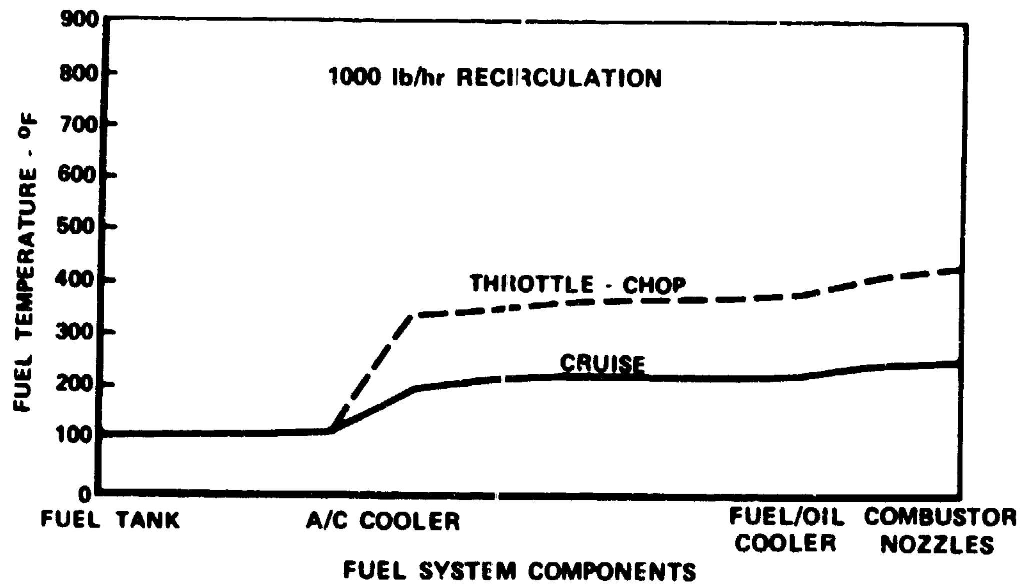


Figure 38. STJ346A Fuel Stream Temperature Profiles

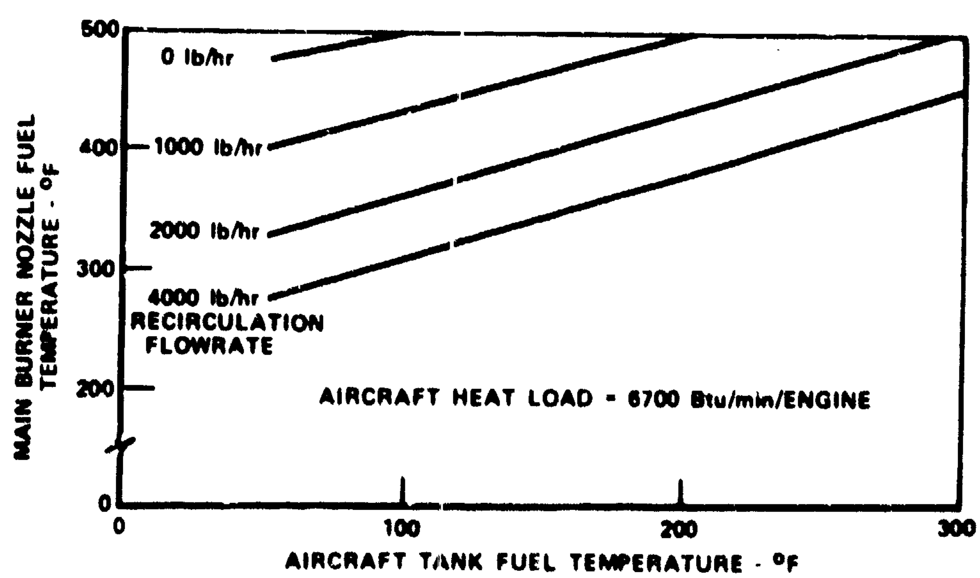


Figure 39. Recirculation Effect on Maximum STJ346A Fuel Temperature

The STJ346A fuel and lubrication system flowrates and temperatures at the time of a reduction to minimum throttle at cruise Mach number are shown in figure 40 for 1000 lb/hr recirculation flowrate. The high engine inlet fuel temperature (394°F) resulted in the lubrication system temperature profile shown in figure 41, which is increased approximately 100°F from steady-state cruise.

b. Parametric Recirculation Data

Fuel recirculation to the airframe reduces the airframe/engine interface temperature, allowing reductions in the engine fuel flow without causing excessive fuel or lubricant system temperatures. The resulting total heat returned to the airframe is low because recirculation is only required for short intervals of time. Parametric curves were prepared for 100, 200, and 300°F tank fuel, 150, 250, and 350°F airframe/engine interface fuel temperatures, and recirculation flowrates from 0 to 4000 lb/hr. An example is shown for using these curves, which were prepared (1) as a design tool for airframe/engine thermal management and (2) for selecting an appropriate fuel. These data were computed for a transient maneuver condition when recirculation would be needed and have the greatest influence at maximum Mach number and cruise altitude. The results illustrate the ability to maintain low engine fuel system temperatures when the engine fuel consumption is too low to cool the total airframe-generated heat load without excessive temperature rise. Care must be exercised, however, to avoid contamination of aircraft tanks with recirculated fuel.

A parametric study of fuel recirculation as a solution to reduce these temperature peaks was conducted assuming reduction of engine power to minimum at maximum Mach number and cruise altitude. This represented a transient condition, since the aircraft could not maintain altitude and speed at minimum power, but represented a possible "worst case" maneuver that the system should be designed to accommodate. The parameters and their ranges of variation are shown in table VI.

Figures 42 through 47 show the following fuel system temperature characteristics under the assumed conditions of fuel temperatures and recirculation flowrates:

- Figure 42 shows the peak fuel temperatures at the burner nozzles for the range of fuel interface temperatures, based on the temperature increase of the fuel in the engine fuel system. The capabilities of candidate fuels are superimposed to show the maximum allowable interface temperatures for each fuel.

- Airframe heat load and fuel recirculation rate effect on airframe/engine interface temperature (figures 43 through 45).

- Airframe fuel tank temperature effect on airframe/engine interface temperature for variable airframe heat load and recirculation flowrate (figures 43 through 45).

- Airframe/engine interface fuel temperature and recirculation flowrate effect on the temperature of recirculated fuel (figure 46).

- The amount of heat load generated in the aircraft that is disposed of in the fuel consumed by the engine (figure 47) as a function of fuel tank temperature and airframe/engine interface temperature.

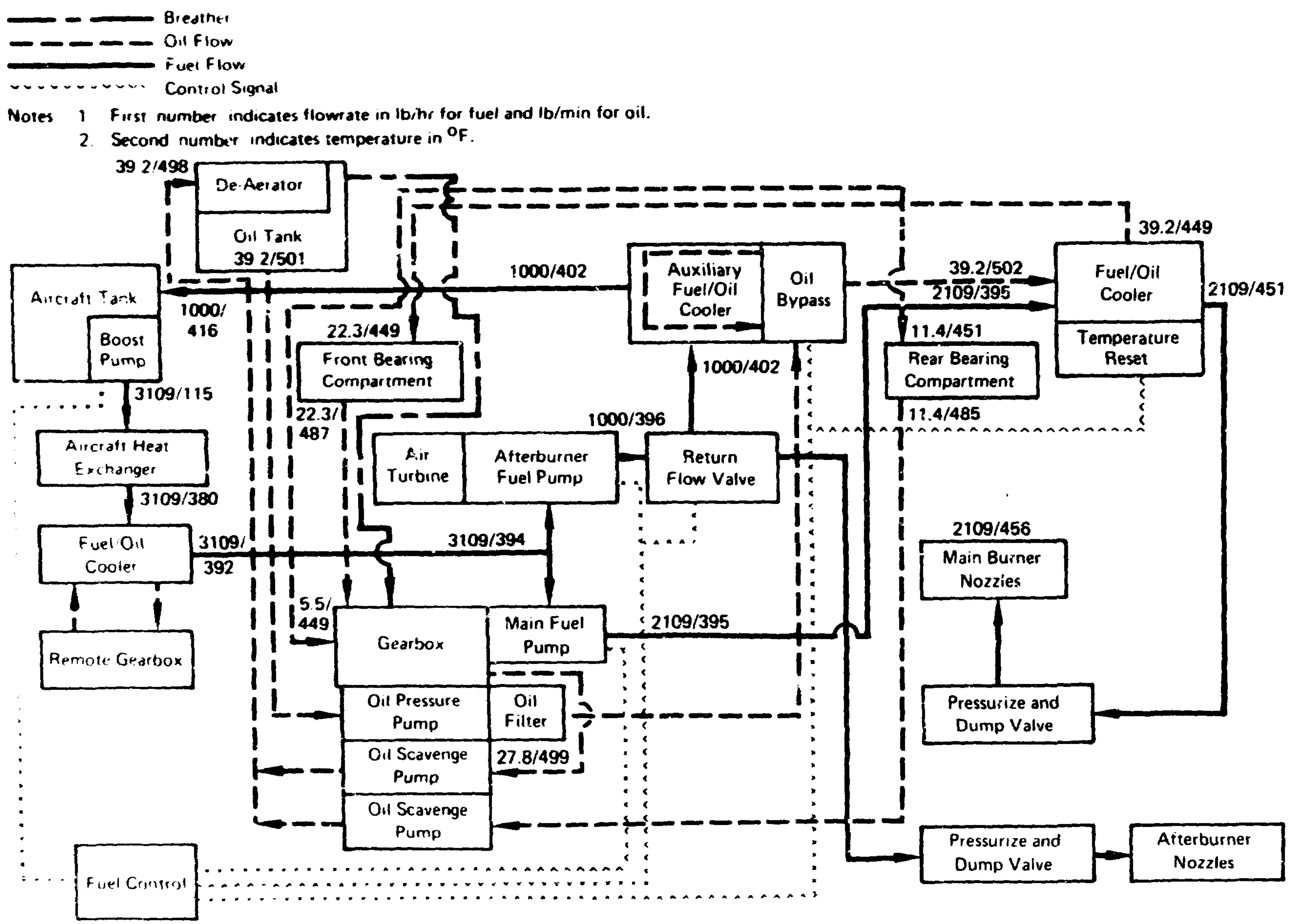


Figure 40. STJ346A Fuel and Lubrication System Flowrates and Temperature When Power Is Reduced to Minimum at Cruise Altitude and Mn

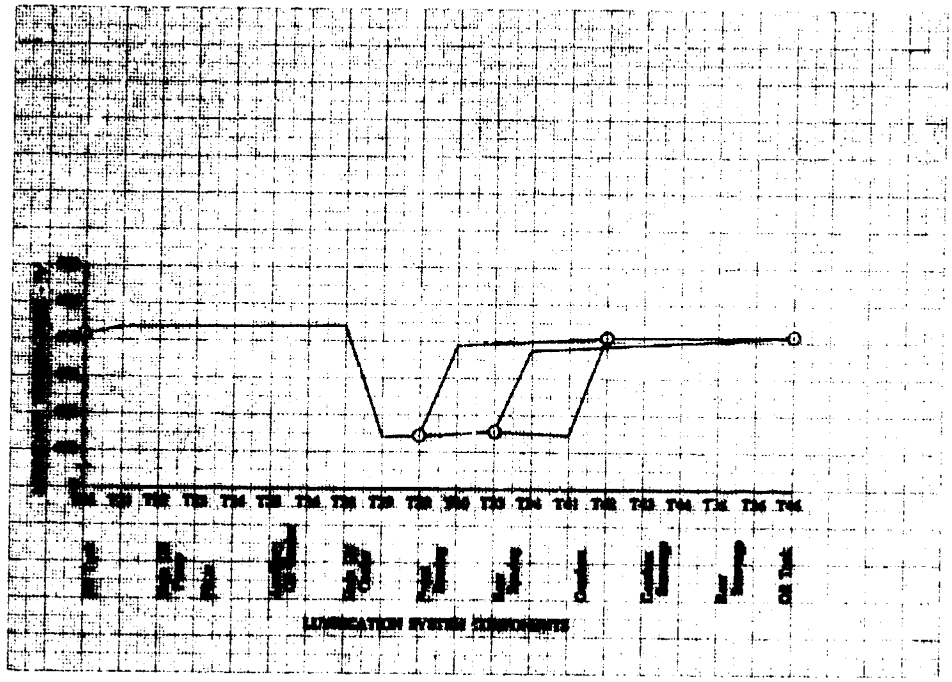


Figure 41. STJ346A Lubricant Stream Temperature Profile When Power Is Reduced to Minimum at Cruise Altitude and Mn

Table VI. Conditions for a Parametric Study of Fuel Recirculation Influences

Tank Fuel Temperature, °F	Airframe/Engine Interface, °F	Recirculation Flowrates, lb/hr
100	120 to 500	0, 250, 1000, 2000, 3000, and 4000
200	220 to 500	0, 250, 1000, 2000, 3000, and 4000
300	320 to 500	0, 250, 1000, 2000, 3000, and 4000

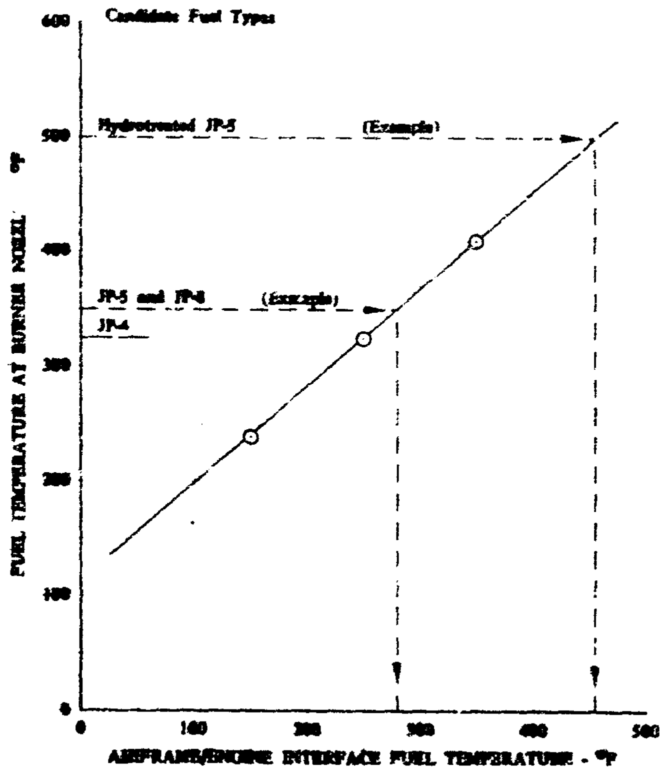


Figure 42. Maximum Allowable Airframe/Engine Interface Fuel Temperatures

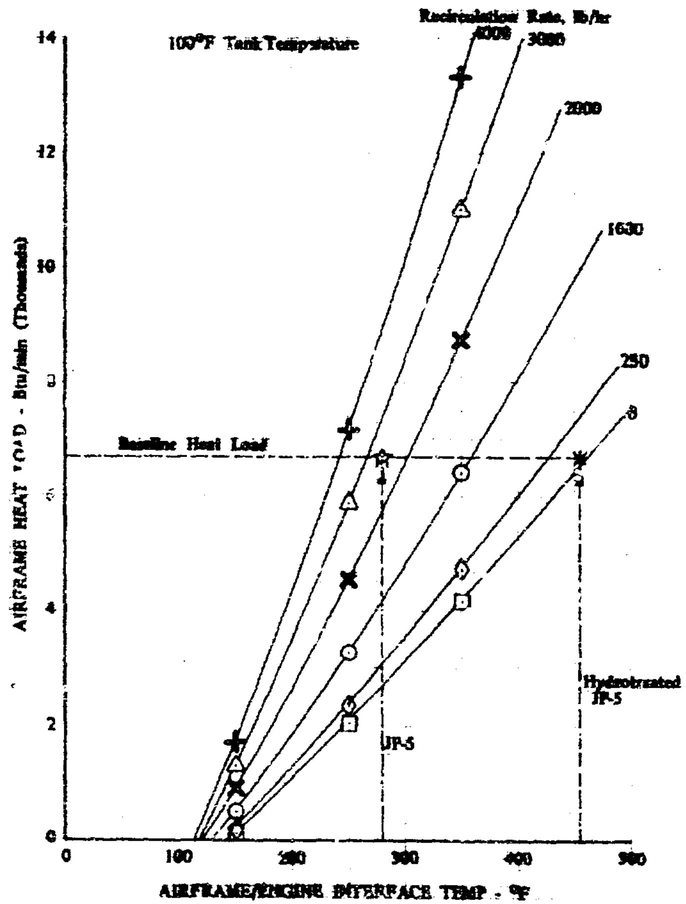


Figure 43. Recirculation Rates and Interface Temperatures for Airframe Heat Input to 100°F Fuel

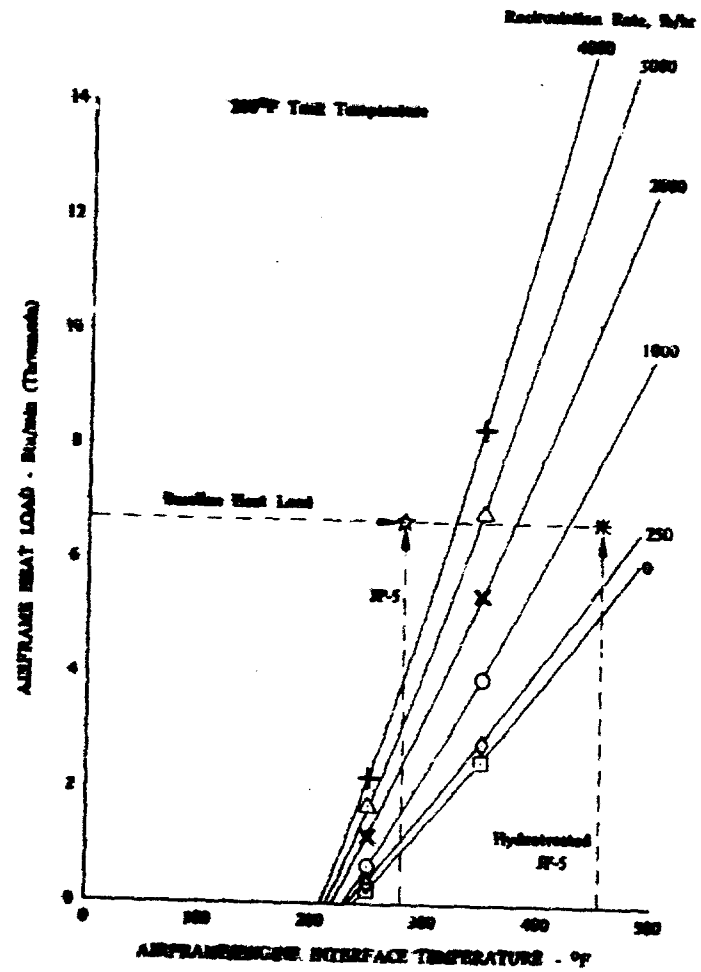


Figure 44. Recirculation Rates and Interface Temperatures for Airframe Heat Input to 200°F Fuel

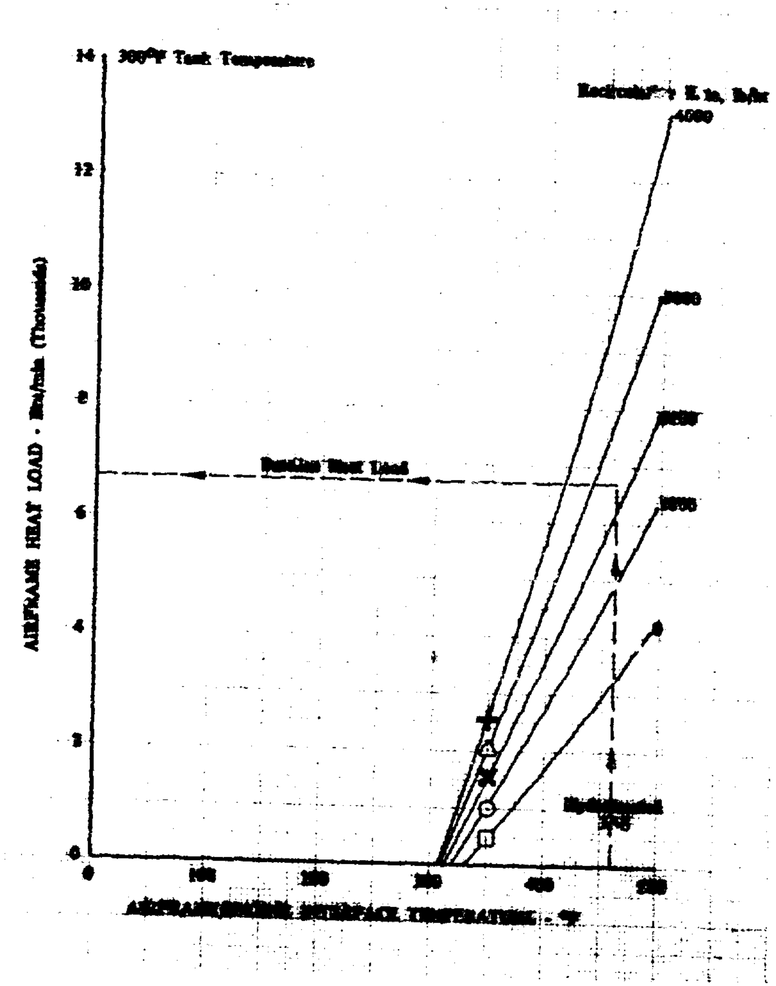


Figure 45. Recirculation Rates and Interface Temperatures for Airframe Heat Input to 300°F Fuel

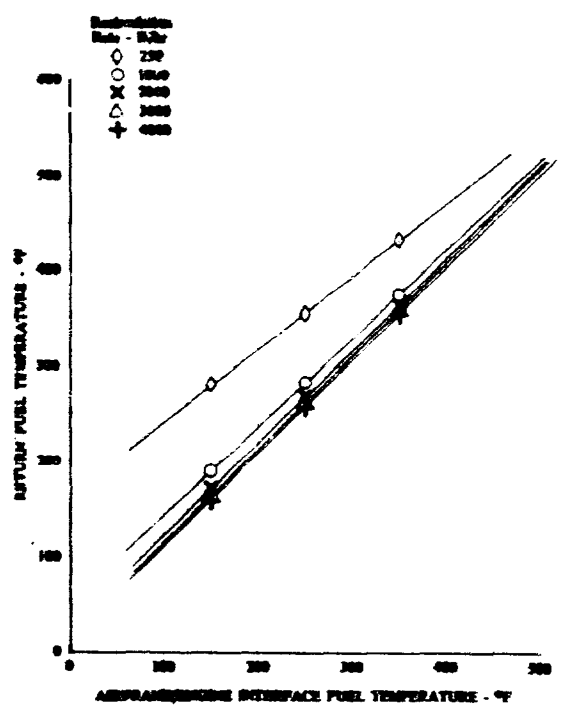


Figure 46. Interface Temperature and Recirculation Flowrate Influence on the Return Temperature

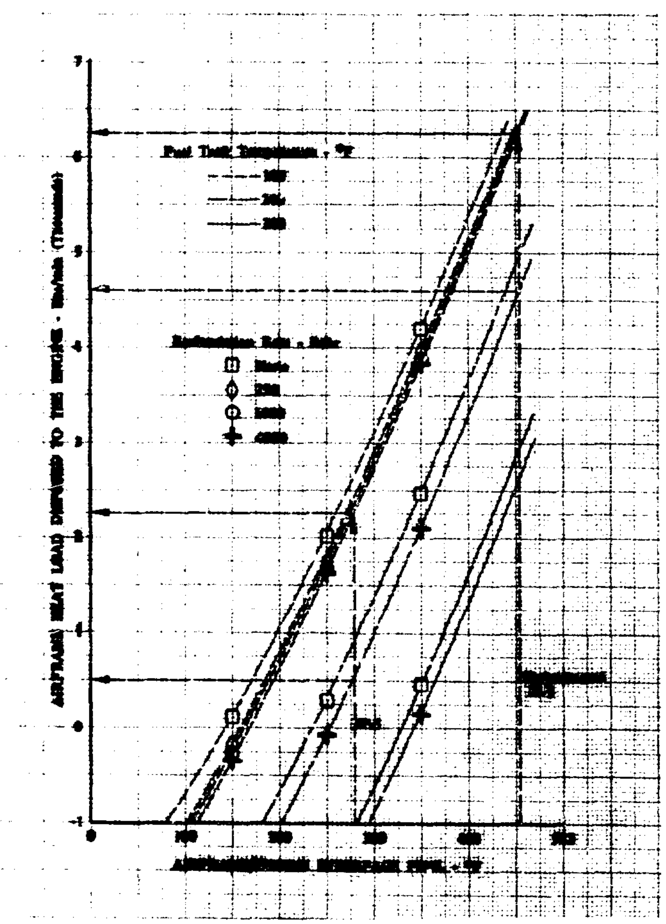


Figure 47. Fuel Tank and Interface Temperature Influence on the Rate of Airframe Heat Disposed in the Engine Fuel Flow

The effects of recirculation flowrates on the airframe/engine interface temperature over a range of airframe heat loads are shown for airframe fuel tank temperatures of 100, 200, and 300°F in figures 43 through 45. As the interface temperature and recirculation flowrate vary, the temperature of the recirculated fuel changes (figure 46). This curve shows that the interface temperature is a primary influence at recirculation flowrates above 1000 lb/hr. Flowrates below 1000 lb/hr begin to cause high recirculation fuel temperatures due to environmental heating influences as shown by the curve for 250 lb/hr recirculation.

Figure 47 shows the rate at which the airframe may dispose of heat in the fuel delivered to the engine. When flow is recirculated, part of the heat load is carried by fuel consumed by the engine; the balance of airframe heat plus environmental heating would return to tanks.

Examples of a way to use these parametric curves are illustrated on the curves in figures 42 through 47. From figure 42, it is determined that the maximum allowable airframe/engine interface temperature would be 280°F for JP-5 fuel or 455°F for hydrotreated JP-5. A total airframe heat load of 13,400 Btu/min has been determined to be representative for the study aircraft and mission, representing 6700 Btu/min per engine. From figure 44, for this heat load and a tank temperature of 200°F, it is shown that fuel flow recirculation of about 700 lb/hr would be required for hydrotreated JP-5 (indicated by an asterisk on the curve) or an estimated 7000 lb/hr for common JP-5 (starred point). Corresponding points, if tank temperature did not exceed 100°F (figure 43), show fuel recirculation could be eliminated using hydrotreated JP-5 or reduced to about 2500 lb/hr using JP-5. Figure 46 provides the temperature of fuel recirculated from the engine. It can be seen that the temperature limit of hydrotreated JP-5 will be exceeded in the return line, at the minimum recirculation rate. Figure 47 shows how much of the 6700 Btu/min airframe heat load would be absorbed in the fuel consumed by the engine. At the 280°F limit of airframe/engine interface fuel temperature for JP-5, this would be 2250 Btu/min for 100°F tank temperature and 500 Btu/min for 200°F tank temperature. At the 455°F limit of airframe/engine interface fuel temperature for hydrotreated JP-5, most of the heat load is absorbed by the engine fuel flow at 100°F tank temperature or 4600 Btu/min for 200°F tank temperature.

Table VII summarizes the example data points shown in figures 42 through 47 and discussed in preceding paragraphs. Required recirculation rates, tank return fuel temperature, and airframe heat load disposed of in engine fuel consumption are determined by specifying fuel type, airframe heat load, and airframe tank temperature for the given minimum power (throttle-chop) at cruise flight conditions. The small environmental heat load added to recirculated fuel is neglected in estimates of heat returned to the airframe fuel tanks by recirculated fuel.

By plotting the data summarized in table VII vs the airframe tank fuel temperature, the recirculation parameters may be determined for airframe fuel tank conditions between 100 and 200°F. The plotted data for the Mach 3+ STJ346A engine are shown in figure 48. The airframe tank fuel temperature was 115°F at the mission point selected for this recirculation study. Figure 48 illustrates how these plots may be used to determine the recirculation requirements (summarized in table VIII) for reducing the STJ346A power to minimum at the end of the mission cruise out.

Under conditions that combine minimum engine power with cruise Mach number and altitude, variances in airframe/engine interface fuel temperature will cause the maximum fuel temperature at the burner nozzles to vary, as shown by the curve in figure 42. This relationship is not influenced by the fuel recirculation rate and establishes the maximum allowable engine fuel inlet temperatures for each candidate fuel. Usually the candidate fuel selection is based on the maximum fuel temperature at the burner nozzles, although conditions could exist wherein the recirculation fuel temperature could be higher due to environmental heating of the return line.

To use hydrotreated JP-5 to the maximum allowable interface temperature at the minimum recirculation flowrate would raise the return fuel temperature above the nozzle temperature. Higher recirculation or lower airframe/engine interface temperatures would be necessary to avoid exceeding the stability limit in the return line and/or prevent recirculation temperatures that could contaminate the bulk fuel.

5. Flight Envelope Conditions

Preceding calculated fuel and lubricant temperatures have covered the baseline mission, alternate interface fuel temperatures during cruise, steady-state but localized "hot spots," and transient maneuvers. An additional investigation was completed to define fuel and lubricant temperatures for the complete flight envelope that would typically be required for an engine with these mission capabilities. Operating points were analyzed at locations encompassing the complete flight envelope defined in Volume I and for a representative range of aircraft/engine interface temperatures at each point.

Table VII. Summary of STJ346A Fuel Recirculation Influences

Airframe Heat Load Per Engine, Btu/min	6700		6700	
Fuel Type	JP-5 and JP-8		Hydrotreated JP-5	
Maximum Allowable Fuel Temperature at Nozzles, °F	350		500	
Maximum A/E Interface Temperature to Not Exceed Nozzle Temperatures, °F	280		455	
Airframe Tank Temperature, °F	100	200	100	200
Recirculation Rate, lb/hr	2600	Over 7000	Between 0 and 250	700
Return Fuel Temperature, °F	290	285	Over 525	490
Rate of Heat Disposal Through Engine Consumed Fuel, Btu/min	2250	500	6250	4600
Rate of Heat Returned to the Airframe Tanks, Btu/min	4450	6200	450	2100

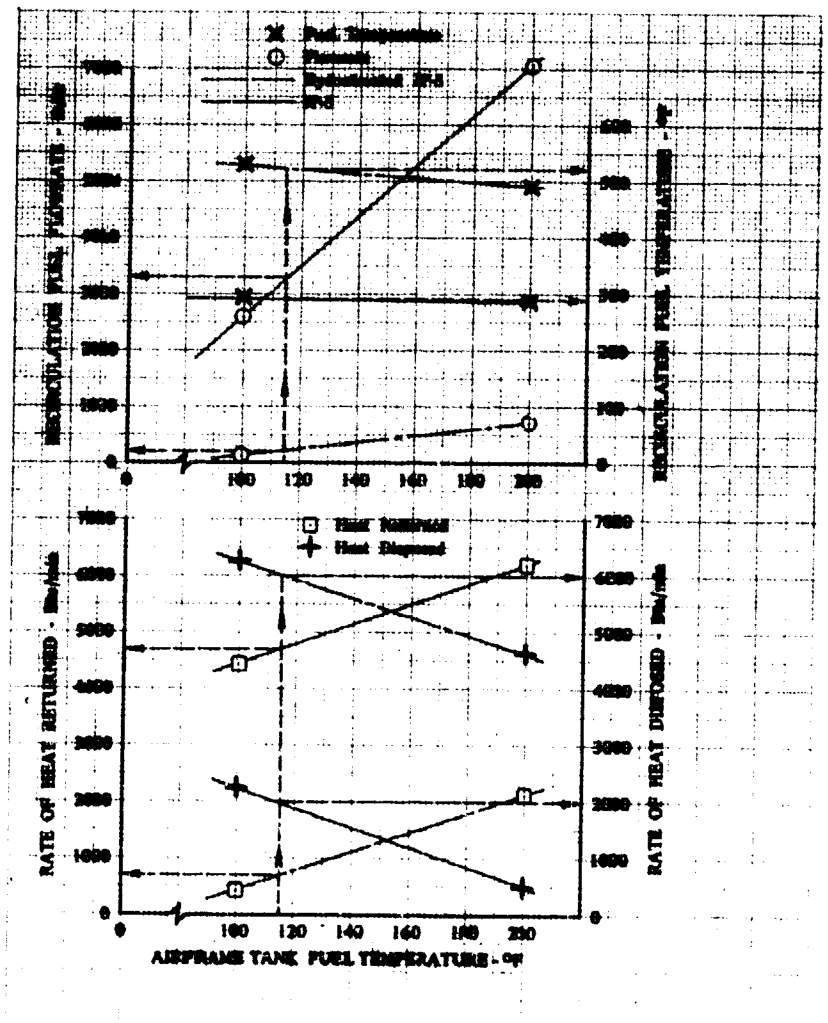


Figure 48. Airframe Fuel Tank Temperature Influence on STJ346A Recirculation Parameters

Table VIII. Summary of Recirculation Parameters for 115°F Airframe Tank Fuel

Fuel Type	JP-5 and JP-8	Hydrotreated JP-5
Recirculation Flowrate, lb/hr	3300	200
Recirculated Fuel Temperature, °F	290	520
Rate of Heat Returned to Airframe, Btu/min	4700	700
Rate of Heat Disposal to the Engine, Btu/min	2000	6000

Temperatures of fuels and lubricants were computed from STJ346A afterburning turbojet engine operating conditions corresponding to steady-state aircraft thrust requirements for 39 points within the entire flight envelope. Computed data were surveyed in 50°F increments in the computer program to determine isotherms. Curves of fuel interface temperatures for three aircraft fuel tank temperatures and an aircraft heat load of 6700 Btu/min per engine were superimposed on the flight envelopes using engine fuel flow requirements, figures 49, 50, and 51. A survey of these data indicated estimated ranges of maximum bulk temperatures for fuels and lubricants for engine/aircraft interface fuel temperatures of 150, 250, and 350°F, as shown in table IX. Since problems of main fuel tank contamination due to recirculation may be experienced at interface temperatures above 350°F, maximum engine fluid system temperatures for interface temperatures above this value were not estimated. Because temperatures were for flight conditions at which prolonged steady-state operation was required, increasing recirculation from the baseline 1000 lb/hr was not a solution to reducing temperature levels.

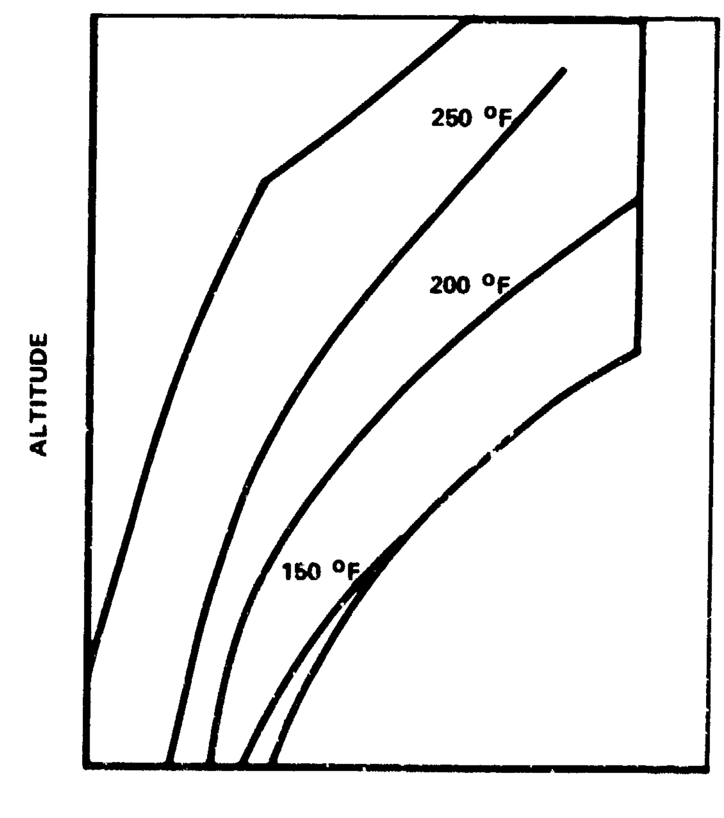


Figure 49. STJ346A Interface Fuel Temperature for 100°F Fuel Tank

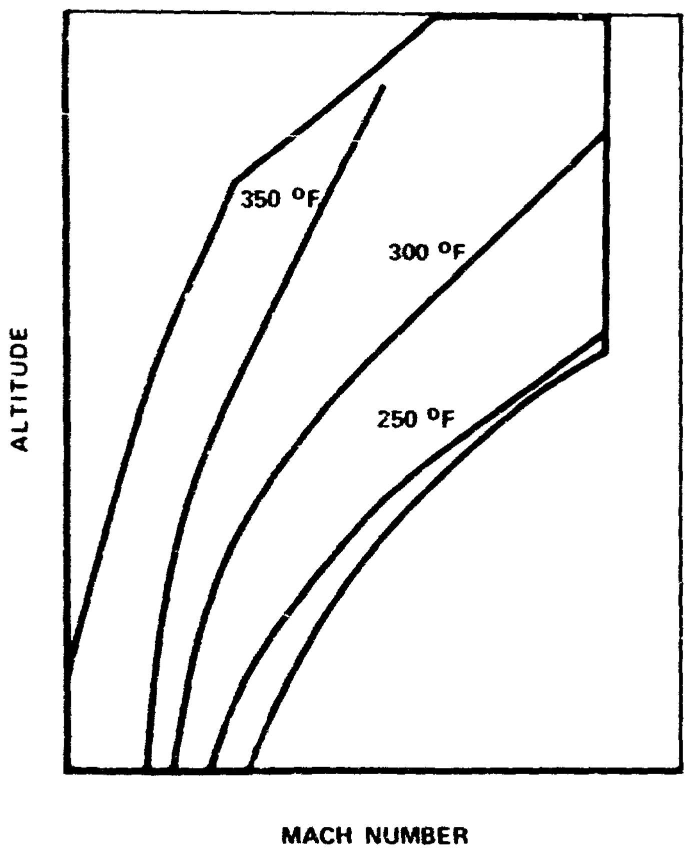


Figure 50. STJ346A Interface Fuel Temperature for 200°F Fuel Tank

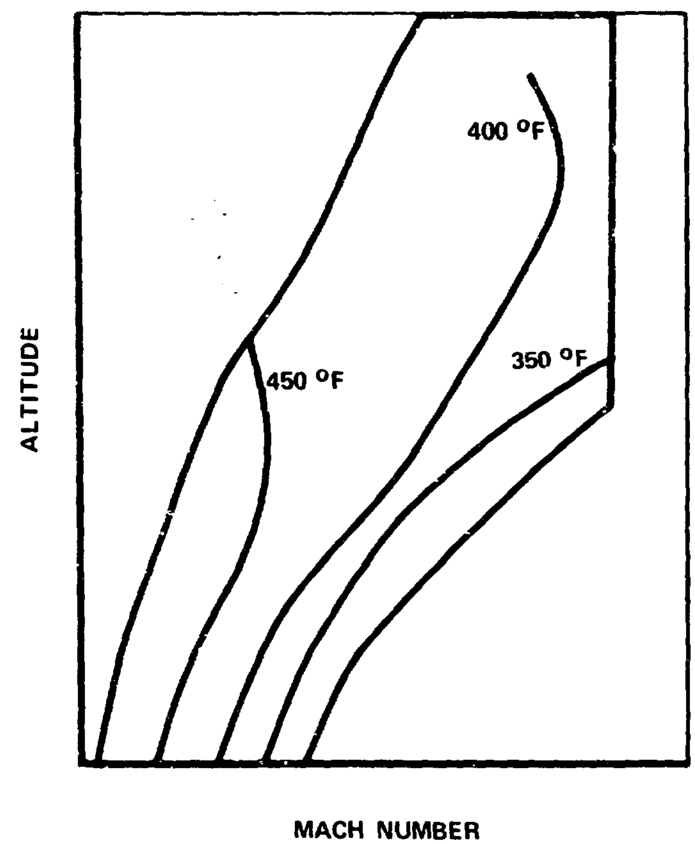


Figure 51. STJ346A Interface Fuel Temperature for 300°F Fuel Tank

Table IX. Range of Maximum Fuel and Lubricant Temperatures for STJ346A Flight Envelope

Engine/Aircraft Interface Fuel Temperature, °F	Maximum Bulk Fuel Temperature, °F	Maximum Bulk Lubricant Temperature, °F	Maximum Recirculation Temperature, °F
150	150 to 250	200 to 250	200
250	250 to 325	250 to 300	250 to 300
350	350 to 500	350 to 425	350 to 400

The preceding analyses were performed with engine/aircraft interface fuel temperature specified independent of aircraft heat load and tank temperature. Figure 49 shows lines of interface fuel temperature that would result from a fuel tank temperature of 100°F engine fuel flowrate, and an estimated 6700 Btu/min per engine aircraft heat load. For steady-state engine operation on the left-hand side of the envelope the fuel flowrate and environmental conditions are such that the interface fuel temperature would approach 300°F. If tank temperature were 200°F, figure 50 shows operation at the left side of the envelope would result in interface fuel temperatures above 350°F. Figure 51 shows that for an aircraft tank temperature of 300°F, the interface fuel temperature would exceed 350°F for most of the flight envelope. Since aircraft heat load would tend to decrease at reduced flight Mach number, the interface fuel temperature would not increase as rapidly with decreasing Mach number as that computed for the constant 6700 Btu/min heat load. However, the trends of these flight envelope data show that operation of the STJ346A engine at low flight speeds, subsequent to heating of fuel in aircraft tanks during high Mach cruise, would be expected to result in interface fuel temperatures exceeding 350°F. Table IX shows this would require fuel with bulk temperature capability above the limit of JP-5 and lubricant with bulk temperature capability of 425°F or better. Because the highest bulk temperatures occur at low Mach number, ram air coolers could be an alternate solution.

E. STJ346A SYSTEM DESIGN INFLUENCES

In the course of the subject studies, several design modifications were made to the fuel and lubrication system of the STJ346A to alleviate high calculated temperatures. These included insulation and arrangement to minimize hot spots in the bearing compartments that were discussed in the previous section. The split of lubricant flow was revised to equalize maximum lubricant temperatures in the bearing compartments, reducing the higher temperature computed in one compartment with the original design. Arrangement and insulation of fluid lines, high efficiencies for advanced components, state-of-the-art system and component designs, and system design integration with the aircraft (including operating constraints) have major influences on fuel and lubricant operating temperatures. None of these modifications to reduce temperatures had a significant effect on weight, thrust or TSFC of the engine. This paragraph discusses these modifications, the technology advancements compared to an operational high Mach engine, use of fuel cooling to improve the engine cycle efficiency, and alternates to the baseline design in system concepts.

1. Lubrication Distribution

Computed lubricant temperatures for the initial design of the STJ346A fuel and lubrication system were higher in the front bearing compartment than in the rear compartment. This resulted from the initial baseline oil distribution assumption and differences in bearing compartment heat generation characteristics. An option was incorporated in the thermal analysis program to balance the bearing compartment discharge temperatures by adjusting the oil distribution. Based on mission and engine operating envelope and reconsideration of the STJ346A gearbox lubrication requirements, the baseline lubrication system flow distribution was revised to reduce the compartment discharge temperature differences in the lubricant stream temperature profiles. The net effect was a reduction in maximum bulk lubricant temperature that was experienced locally in the front bearing compartment.

Computations for the baseline fuel and lubrication systems for the STJ346A engine showed that the oil discharge temperature from the front bearing compartment was significantly higher than the discharge temperature from the rear bearing compartment. The unbalanced thermal stresses on the lubricant are shown by stream temperature profiles at several mission analysis points in figure 52. These differences in bearing compartment oil discharge temperatures resulted from the baseline assumption of equal oil flow splits to each compartment and the different heat generation characteristics of the front thrust bearing and the rear roller bearing.

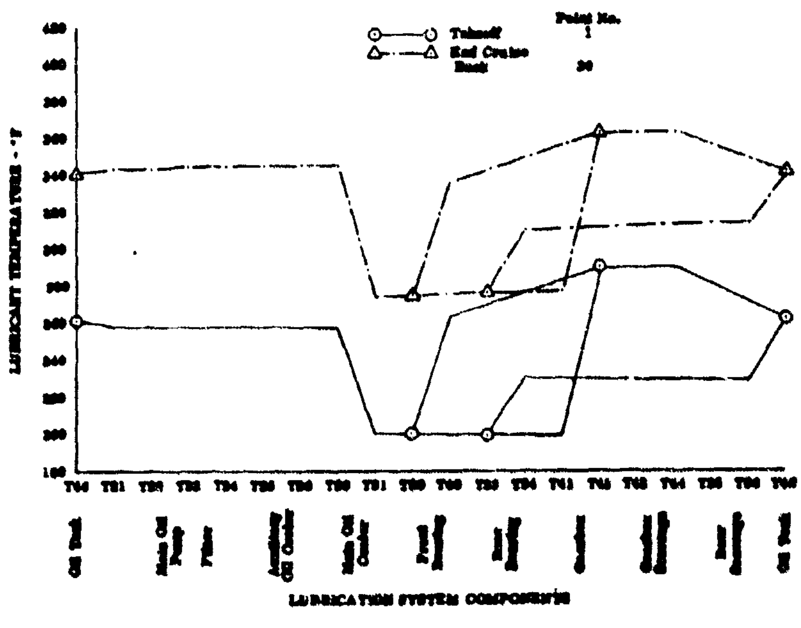


Figure 52. STJ346A Lubricant Stream Temperature Profiles With Equal Bearing Oil Flows

To correct this problem, a thermal analysis program option was incorporated to compute the required oil distribution between the bearing compartments so that the discharge temperatures would balance. Figure 53 shows the required oil distribution during the missions and the degree of variation that would be required for continuously balancing the bearing compartment oil-out temperatures of the STJ346A engine.

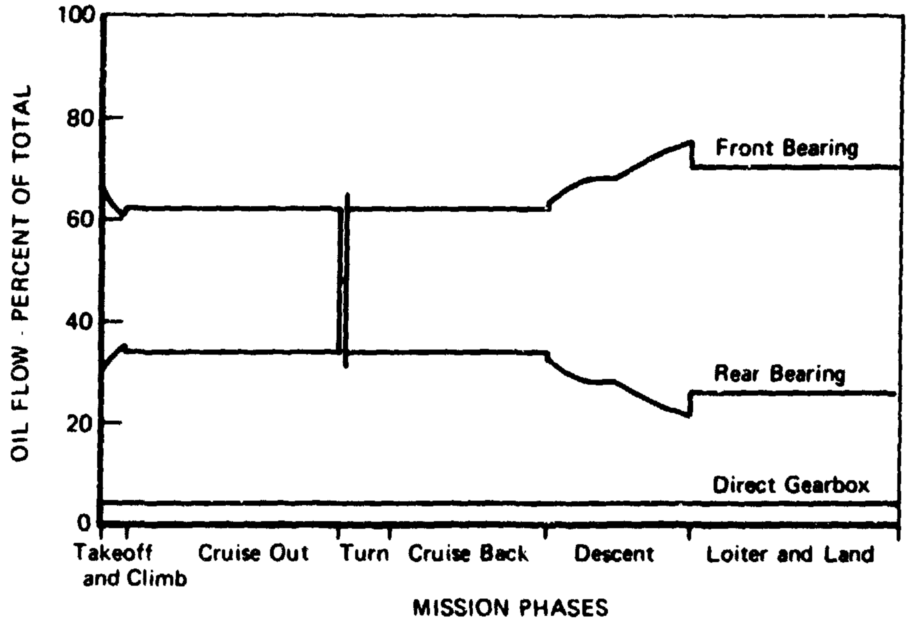


Figure 53. Required STJ346A Bearing Compartment Oil Flow Distribution to Balance Oil Discharge Temperatures

The engine's operating envelope was also considered in determining the best oil distribution to maintain for each engine system. For engine thrust levels established by the requirements for steady-state aircraft operation outside the baseline mission, figure 54 shows the calculated oil distribution to balance the bearing compartments oil discharge temperatures for 39 points in the STJ346A operating envelope. The STJ346A direct gearbox oil flow had been baselined at 4% and amounted to approximately 2 to 3 lb/min during the mission. Reconsideration of the gearbox lubrication requirements indicated that the direct oil flow should be increased to 8 to 10 lb/min, thus increasing the total engine oil flowrate. In summary, the STJ346A baseline engine oil system total flow was increased 16% to provide the additional gearbox flow, and the front bearing compartment flow of both engines was increased on the basis of the mission and operating envelope evaluations, as shown in table X.

Lubricant stream temperature profiles, defined by thermal analysis of the baseline fuel and lubrication systems with the revised flowrates, are shown in figure 55 for the STJ346A engine. The mission analysis points, selected for these lubricant stream temperature profiles, are comparable with the initial baseline plots presented in figure 52 and show the improved balance in the bearing compartment oil-out temperatures. With the revised flow distribution, the lubricant discharge temperature spread of the STJ346A bearing compartments and gearbox have been reduced during the mission, as shown in figure 56. The thermal analysis program option to balance bearing compartment oil discharge temperatures is a useful tool for calculation of the required oil distribution for the preliminary design of new engines.

2. Operating Mode Alternative

The baseline evaluation of the fuel and lubrication system showed a high temperature peak at the start of the mission turn. This temperature peak in each engine system was caused by a combination of low engine fuel flows, aircraft

heat loads, and assumed aircraft fuel management practices. By revising the mode of engine operation at the start of the turn, consistent with aircraft flight characteristics, it was possible to increase fuel flow (increased thrust) and eliminate the fuel and lubrication system temperature peak from this phase of the mission. This provides an example in which the interaction of engine/aircraft interfaces and aircraft maneuvers can be adjusted to eliminate a limiting fuel and lubricant condition in the engine. In this example, the aircraft turn maneuver was accomplished without significant change in time and fuel consumed; however, it also showed that constraints to the operational flexibility of the aircraft can be imposed by the characteristics of existing fuels and lubricants.

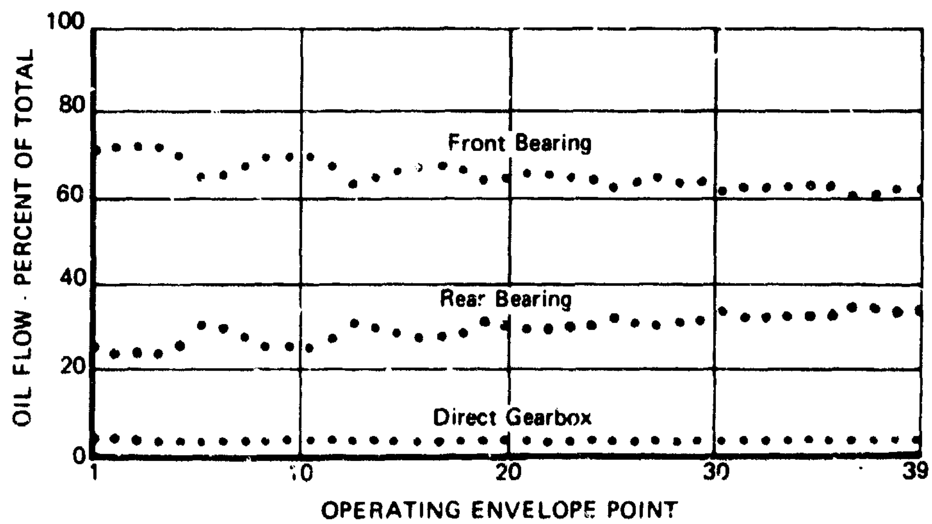


Figure 54. Required STJ346A Bearing Compartment Oil Flow Distribution to Balance Oil Discharge Temperatures (Operating Envelope at Thrust, Required for Steady-State Aircraft Operation)

Table X. STJ346A Baseline Lubricant Flow Redistribution

Bearing Compartment	Distribution - Percent of Total Flow: Initial Assumption	Revision
Front	48	57
Rear	48	29
Gearbox	4	14
		(Total STJ346A oil flow increased 16%)

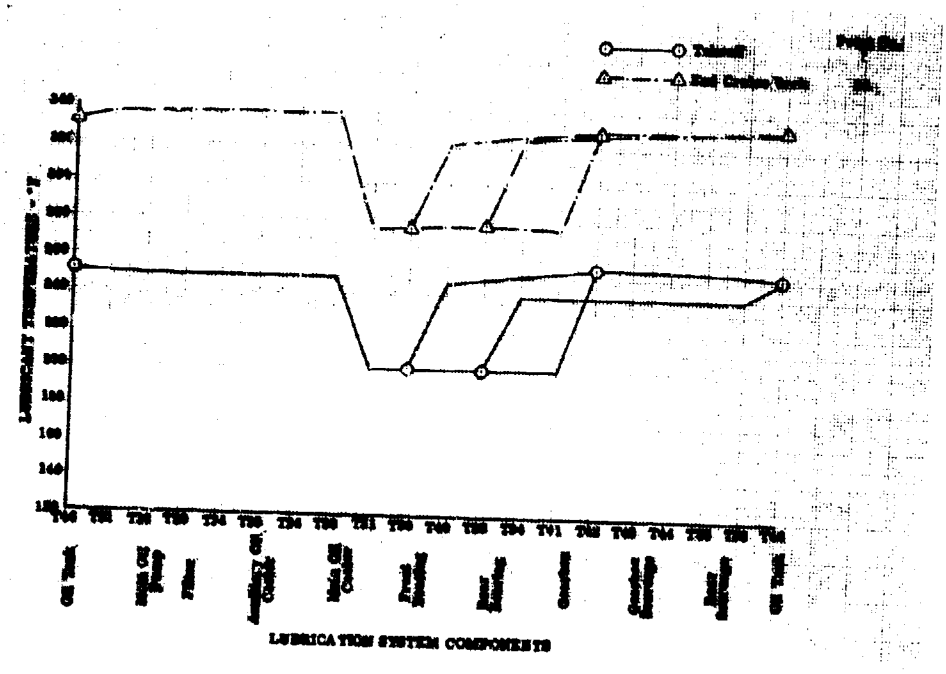


Figure 55. STJ346A Lubricant Stream Temperature Profiles With Revised Oil Flow

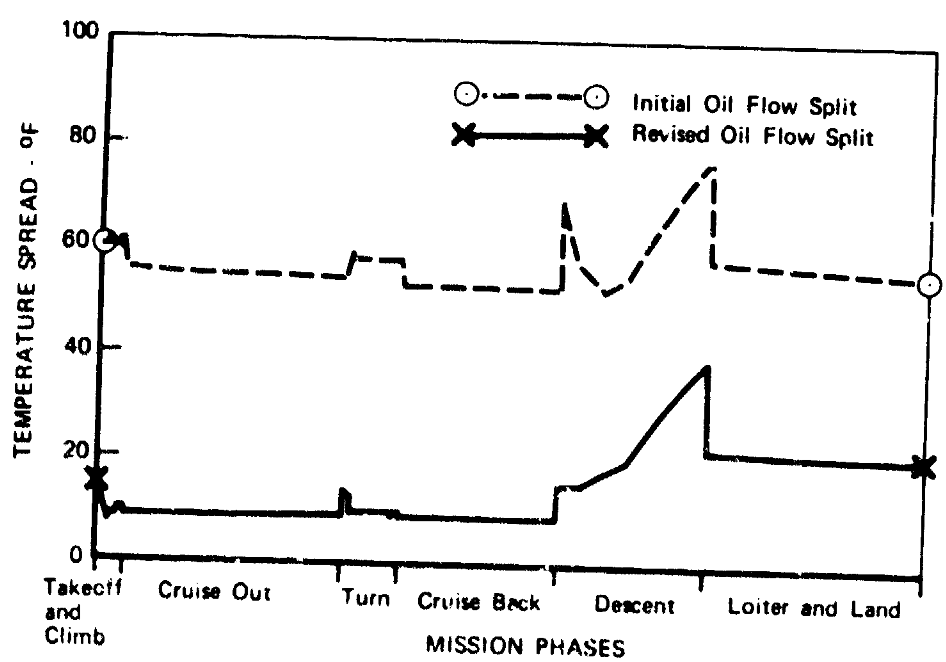


Figure 56. Reduced STJ346A Bearing Compartments and Gearbox Lubricant Discharge Temperature

For the original mission, a combination of factors caused a rise in system temperatures (lubricant peak of 550°F) at the beginning of the turn. Causes included a low engine powersetting (low fuel flow) for a short time interval, total airframe heat transferred only to the fuel consumed by the engine, and no heat returned to the airframe (no fuel recirculation). The engine fuel flow was low because thrust was reduced to the minimum for a maximum rate of descent to the turn altitude. The total airframe heat load was being absorbed by the fuel supplied to the engine and resulted in a high airframe/engine interface temperature. The fuel flowrate from the aircraft was not increased above the engine's fuel consumption requirements as it might have been to reduce the interface temperature and provide for return of excess fuel and associated heat content to the airframe. None of these assumed conditions are strict requirements for performance of the turn maneuver.

By revising the engine and aircraft mode of operation during the turn, it was possible to change the conditions contributing to the fuel and lubrication system temperature spikes. The operating mode change is shown in figure 57. The original turn assumed a drop from the cruise altitude to a lower altitude where a constant altitude, Mach number, and "g" load turn was made. The descent was made as rapidly as possible by reducing the thrust to minimum and losing altitude as a trade to hold the cruise Mach number. The turn and climb back to the optimum cruise altitude were then made at maximum engine thrust. The engine operating mode can be changed to accomplish the turn in a different manner (as suggested by McDonnell Douglas during a program review). At the end of the cruise out, the thrust can be increased to maximum and the mission required "g" load turn started. Because the thrust available is lower than the thrust required, the start of the turn is accompanied by a descent to maintain the cruise Mach number. As shown in figure 58, this change in the fuel flowrates during the first part of the turn results in the elimination of the fuel system high temperature spike from this phase of the mission, as shown in figure 59.

3. Fuel Distribution System

The fuel plumbing system to distribute fuel flow from the engine fuel pumps to achieve proper combustion must be carefully arranged and insulated to minimize environmental heating in high Mach engines. Fuel lines exposed to compressor discharge and combustion gases, in particular, must be minimized in exposed area, and flowrates in distribution lines must be sufficient to limit temperature rise. These desires conflict with those for adequate dispersal of fuel for high combustion efficiency and uniform combustor exit temperature patterns requiring trade studies to resolve an optimum design. Rerouting of fuel lines and added insulation reduced fuel temperatures up to 50°F from the first trial design of STJ346A fuel manifolds. A low number of fuel nozzles in the initial design is compared below with a revised distribution system consistent with demonstrated technology, showing the fuel temperature sensitivity.

The main burner nozzle (figure 60) uses a single support for each nozzle to minimize the surface area exposed to compressor discharge pressure, temperature, and velocity. Estimated maximum fuel nozzle spacing for 1978 technology resulted in 30 primary burner nozzles in the original design. To show the influence of this technology, the number of nozzles was doubled to 60, so that the nozzle spacing is similar to burner rig and ATEGG experience. Additional fuel manifold distribution lines with lower flow per line are needed to supply these nozzles.

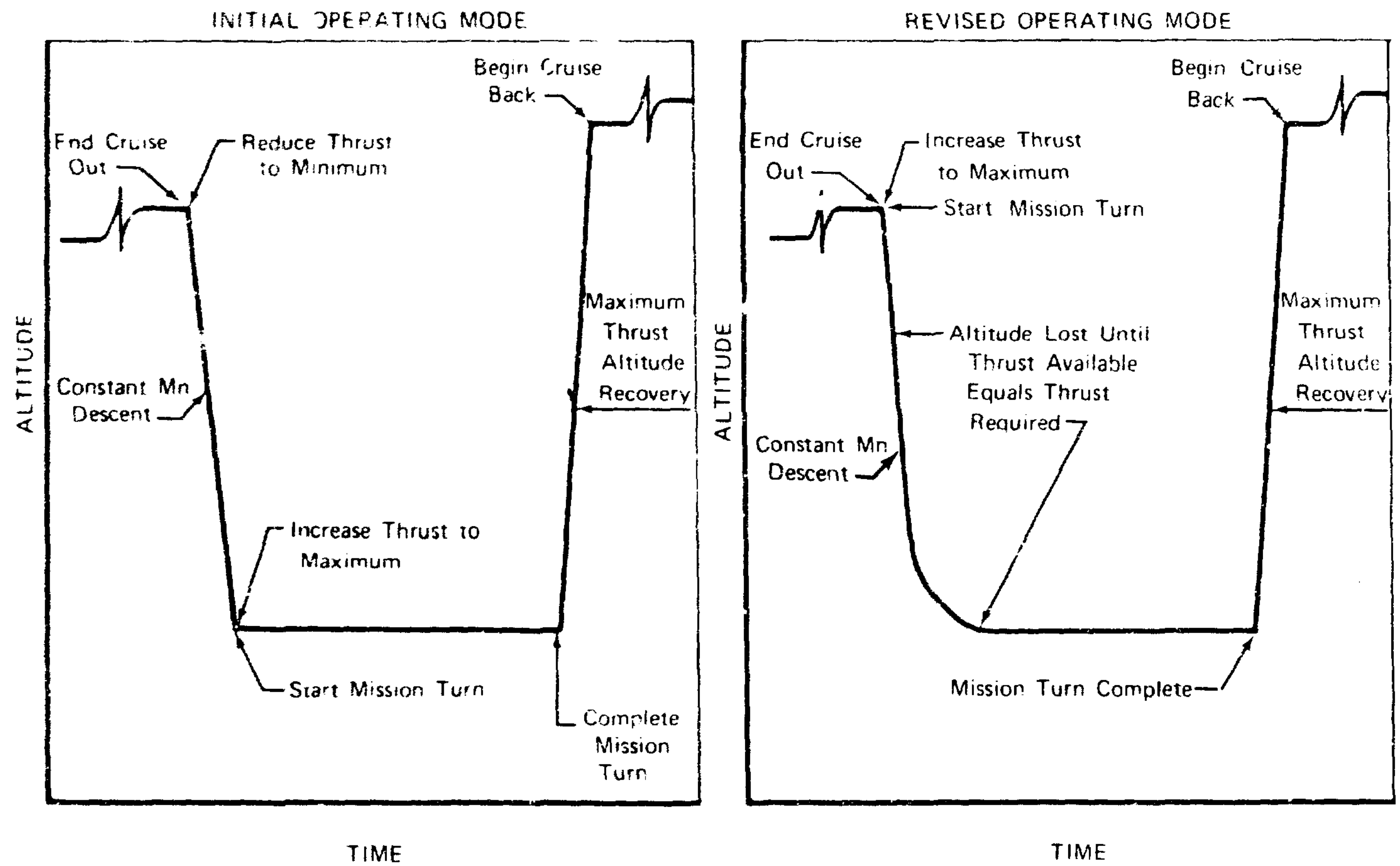


Figure 57. Engine Operating Mode Change During the Mission Turn Analysis

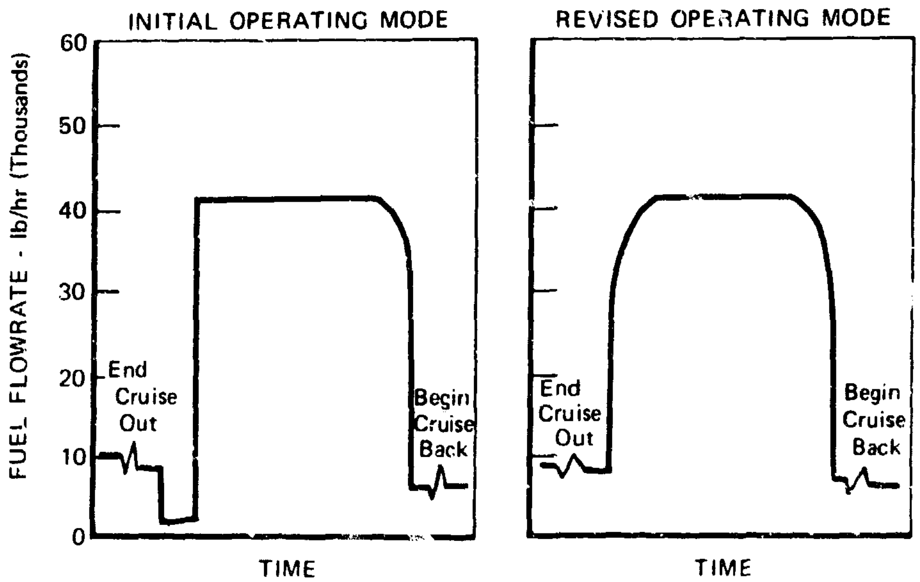


Figure 58. Influence of Mission Turn Operating Mode on the STJ346A Fuel Flowrate

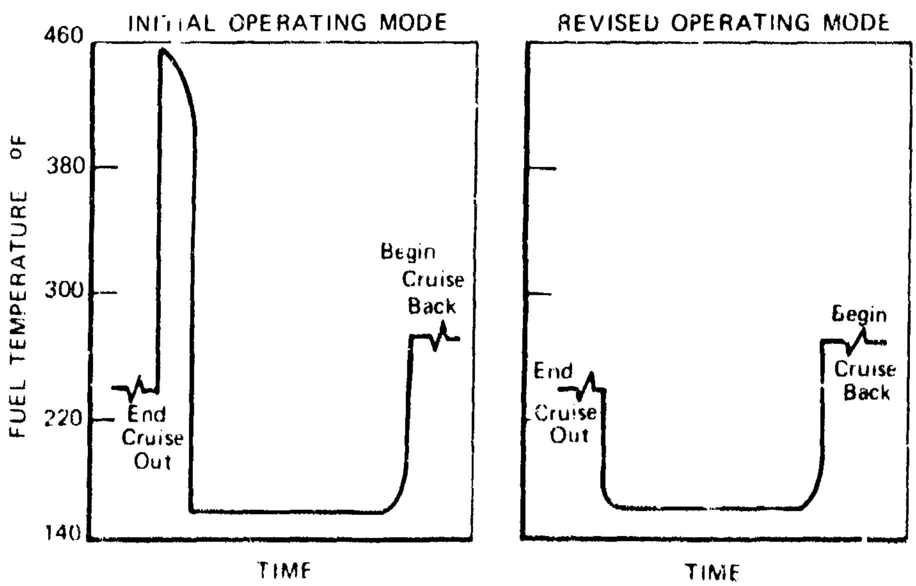


Figure 59. Influence of Mission Turn Operating Mode on the Maximum STJ346A Nozzle Inlet Fuel Temperature

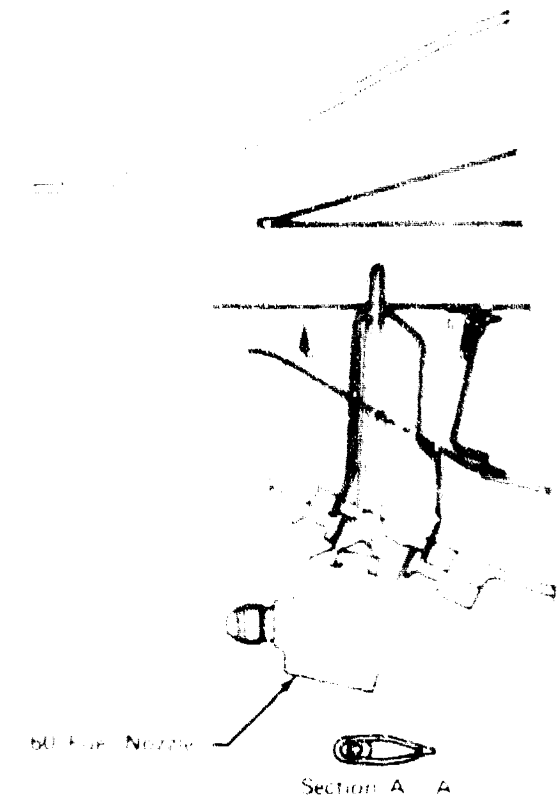


Figure 60. STJ346A Individual Main Burner Fuel Nozzle Supports

The afterburner spraybars shown in figure 61 were also increased in number (from 20 to 30) and the corresponding manifold line changes made. The variable orifice and heat-shielded designs are based on current FRDC experience for tube size and shield configuration. Because spraybars are radial, they may be integrated with turbine exhaust case struts and airflow-straightening vanes. The number and spacing of nozzles are similar to those for the J58 high Mach number afterburning turbojet.

These modifications increased the maximum baseline fuel temperatures at the nozzles less than 20°F, as shown in figure 62. The increased temperature during cruise and the decreased fuel temperature during the descent and loiter were primarily caused by ambient influences on the additional exposed surfaces of manifold distribution lines and lower flows in each of the increased number of manifold lines.

4. Influence of Advanced Component Technology

For comparable inlet conditions, the maximum fuel and lubricant temperatures in the STJ346A engine were calculated to be approximately 200°F and 100°F lower, respectively, than those experienced in the J58 engine operation, although the engine cycles, sizes and flight conditions are similar. The designs of the fuel and lubrication systems for the two engines were compared to check the STJ346A engine analyses and define the most significant design differences contributing to these lower maximum fluid temperatures.

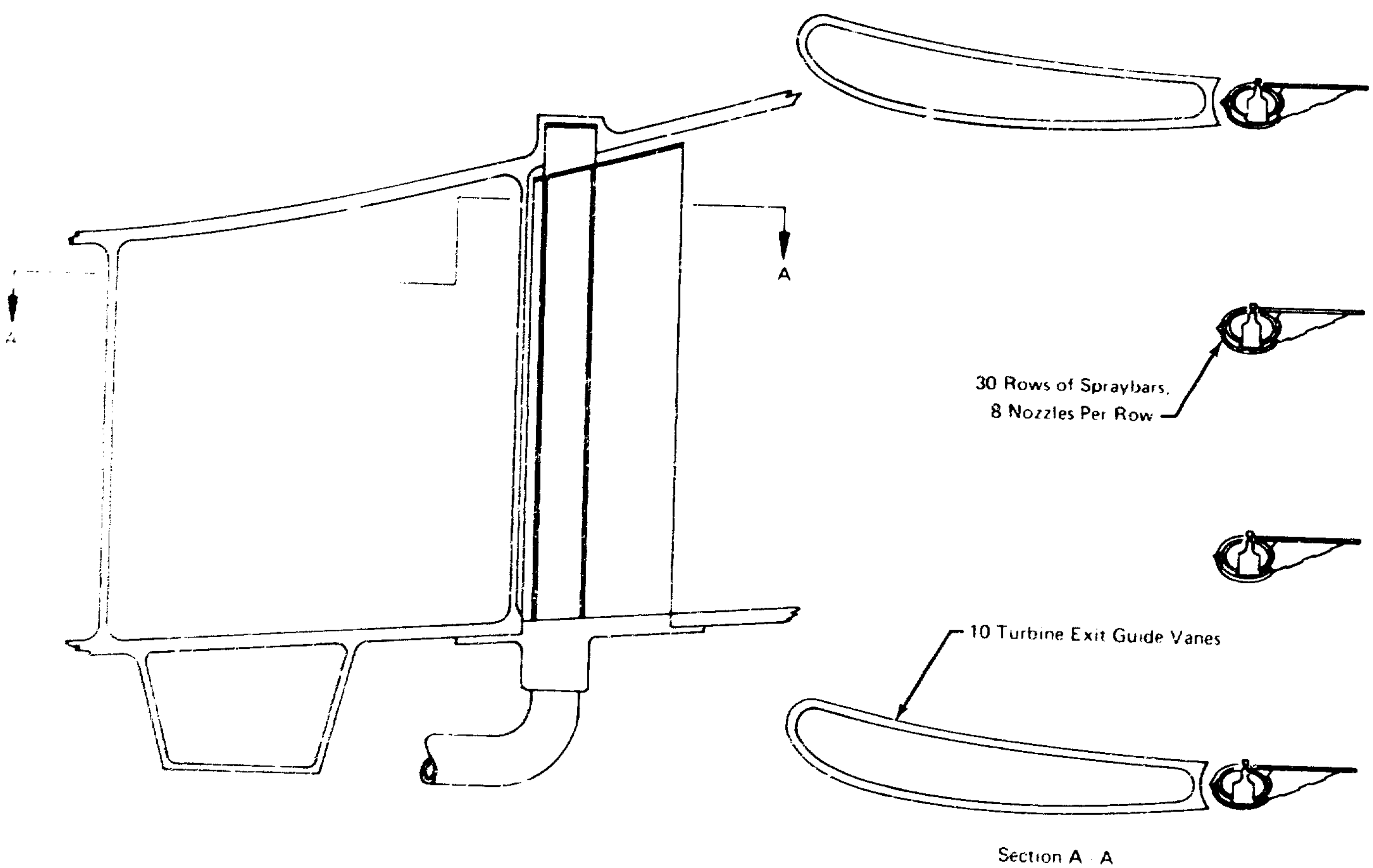


Figure 61. STJ346A Afterburner Spraybars Integrate With the Turbine Exhaust Vanes

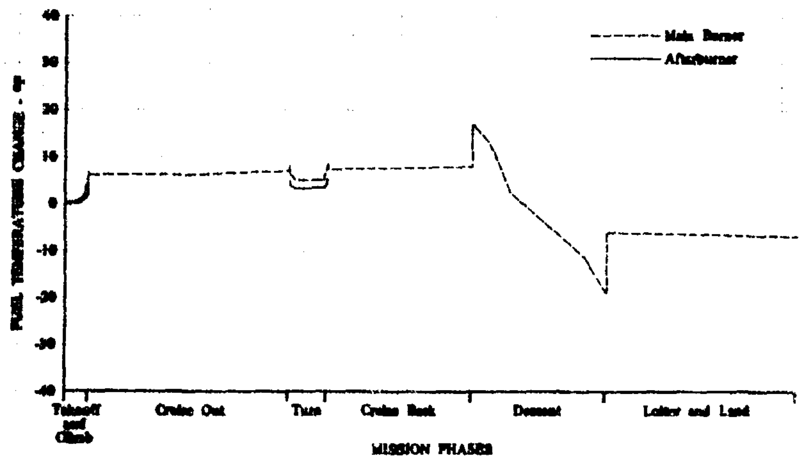


Figure 62. STJ346A Maximum Nozzle Fuel Temperature Changes Resulting From Modifications

Comparisons were made by a small adjustment of the STJ346A fuel flows and inlet fuel temperature at one mission analysis point that was close to available J58 test data. The results of the study attributed the low heat loads and system temperatures of the STJ346A to the basic design of components and systems.

The J58 fuel system schematic is shown in figure 63. The fuel system components that are not used in the STJ346A include (1) the hydraulic pump, (2) hydraulic actuators for the starter bleed, compressor bleed, inlet guide vanes, and exhaust nozzle, (3) gas generator boost pump, and (4) recirculating control loops.

These J58 components cause large increases in fuel temperature prior to using the fuel for lubricant cooling. This sets a basic limit to the minimum lubricant temperature. The J58 lubrication system schematic is shown in figure 64. The bearing compartments and gearboxes have higher lubricant heat loads compared with the STJ346A fuel and lubrication system. Comparison of the heat generation and stream temperature profiles of these systems show many small component differences and several large influences contributing to the lower thermal loads for the STJ346A fuel and lubrication system.

The comparison of the two afterburning turbojet engines was made for similar flight conditions by adjusting the STJ346A engine fuel inlet temperature and flow to closely match available J58 fuel system temperatures at similar cruise conditions. The engines were nearly the same design airflow size, rotor speeds were identical, and other conditions were normalized by adjusting the STJ346A inlet fuel temperature, turbojet fuel flow, and afterburner to match the J58 data.

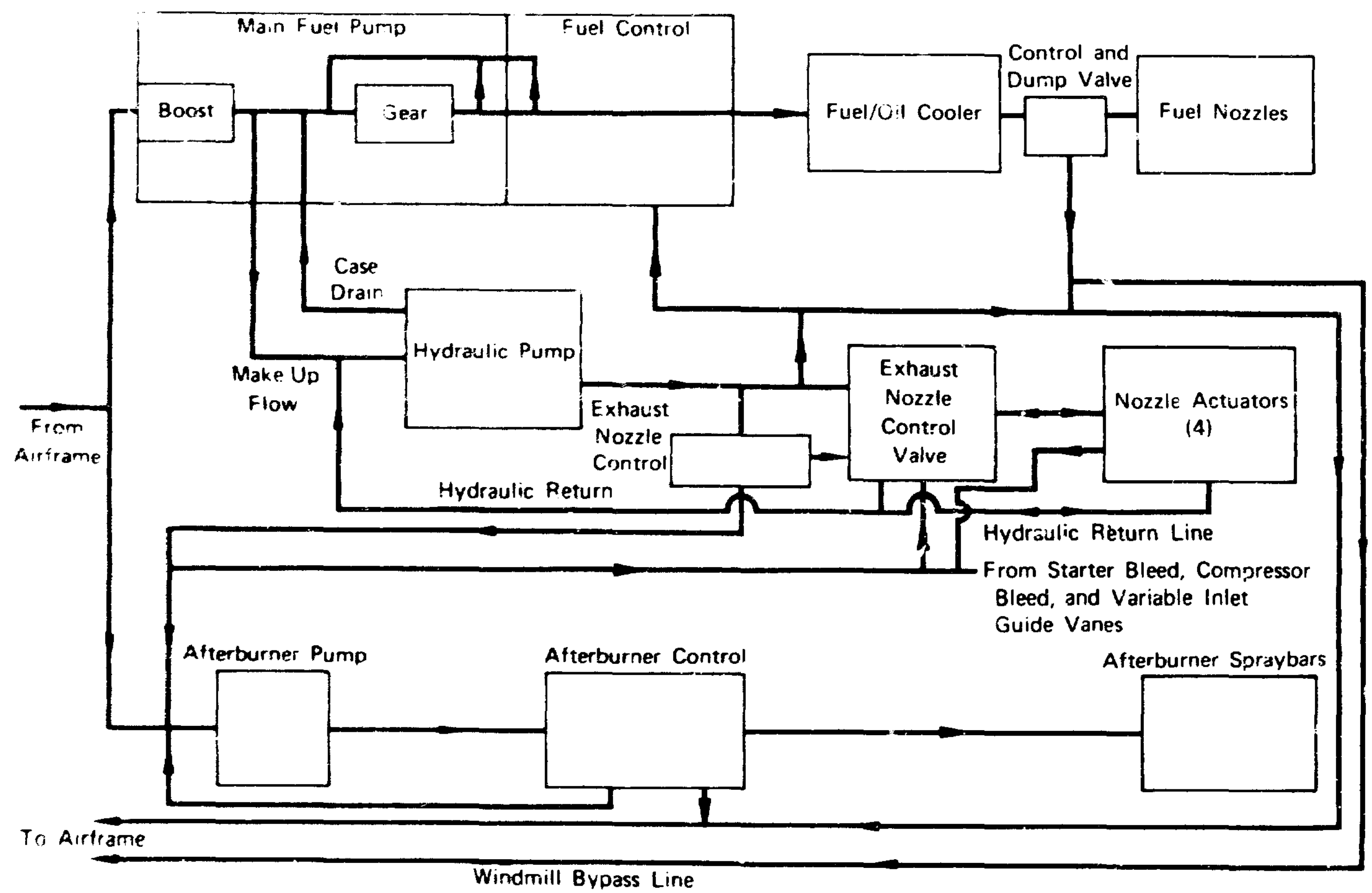


Figure 63. J58 Fuel System Schematic

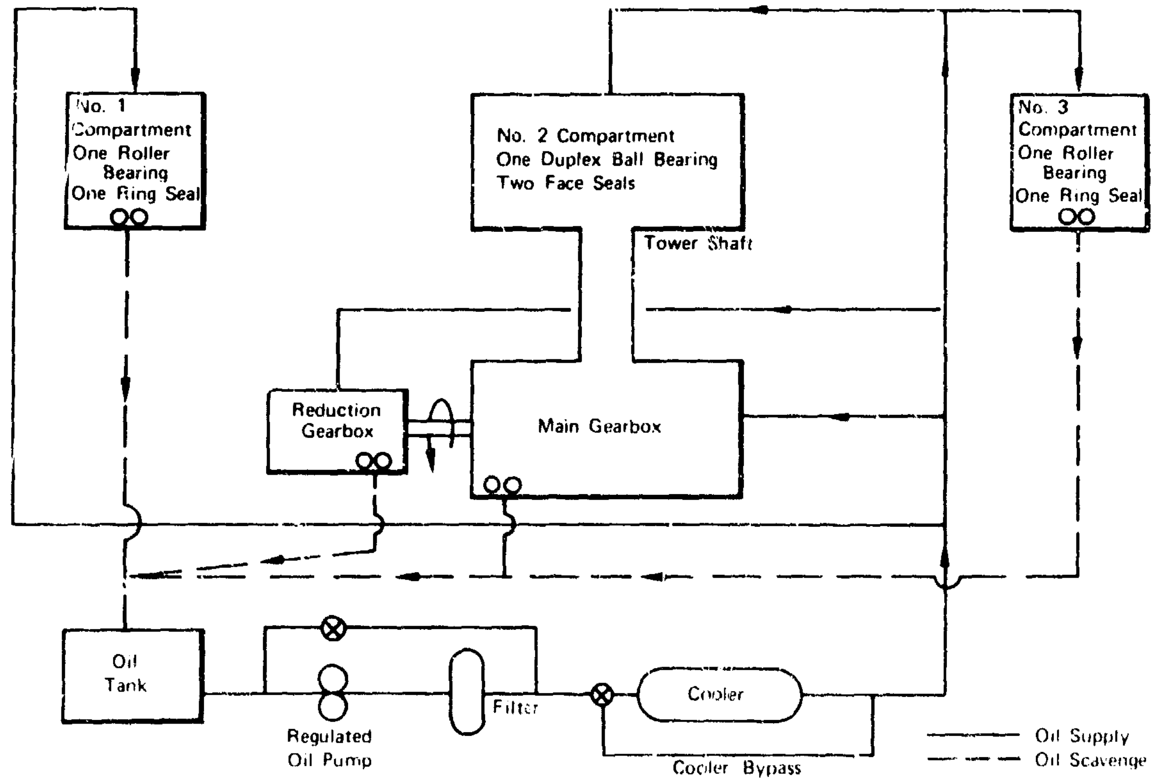


Figure 64. J58 Lubrication System Schematic

Fuel system stream temperature profiles, from the engine inlets to the fuel nozzles, shown in figure 65, illustrate the major differences between the measured J58 and calculated STJ346A fuel temperature increases. The largest STJ346A fuel system temperature rise was attributable to the fuel/oil cooler, while the J58 system had three major temperature increases caused by the hydraulic system, the fuel/oil cooler, and the fuel nozzles. Initial fuel temperature increases of 10°F and 70°F in the J58 resulted from the fuel boost pump and the hydraulic system that were not used for the STJ346A engine. It has been assumed that, in future high Mach number applications, the engine fuel boost pump can be eliminated to conserve fuel heat sink, adding little to the aircraft boost pump supply requirements. Without boost, the main pump will not meet present specification requirements for minimum vapor/liquid ratio, but this compromise was judged to be acceptable considering that only low vapor pressure fuels can be used and the necessity to minimize fuel system heat generation. The hydraulic system is not required by the STJ346A engine because variable engine geometry is operated by air motors. The STJ346A engine was designed to minimize environmental oil heating and has one less bearing compartment than the J58, resulting in total lubrication system heat generation about half that of the J58, and a correspondingly lower fuel temperature rise for the fuel/oil cooler. Significantly lower fuel temperature rises in manifolds and fuel nozzles for the gas generator and augmentor in the STJ346A engine resulted from special design considerations to minimize the high environmental heating caused by close proximity to combustion areas. Experimental work is needed to develop and verify these advanced techniques.

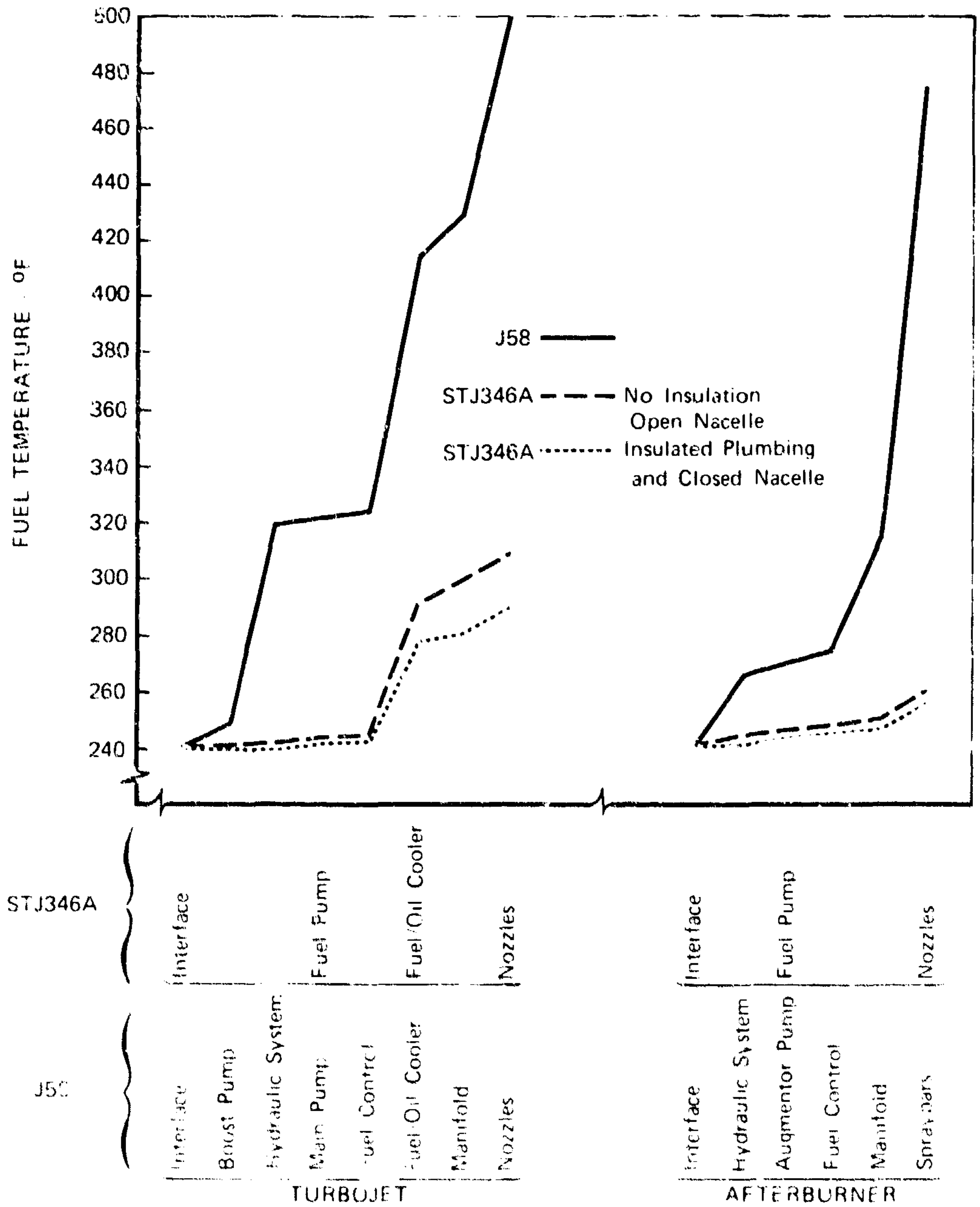


Figure 65. STJ346A and J58 Fuel Stream Temperature Profile Comparison

A final rise of 70°F in the J58 fuel stream profile occurs in the main burner at the last nozzle in multiple nozzle clusters. In the STJ346A, the fuel temperature rise at the nozzles was reduced to 10°F by elimination of internal fuel manifold nozzle clusters (that are exposed to high gas path temperatures and have low fuel flowrates at the last nozzle in a series) and the incorporation of individual nozzle supports with higher flowrates per nozzle.

The comparatively low fuel temperature rise in the STJ346A afterburner stream temperature profile was based on 20 single-nozzle spraybars, while the

J58 fuel temperature results from a more extensive fuel distribution system requiring several sprayrings with multiple orifices. Experimental afterburner work would be needed to determine that the STJ346A type of fuel distribution system would provide suitable afterburner performance and that such low fuel temperature rises can be achieved.

Bar chart comparisons of STJ346A and J58 heat rejection by major subsystem are shown in figure 66. Because fuel flowrates are the same, their relative magnitudes correspond to the fuel temperature rises shown in figure 65. Figure 67 further breaks down these heat rates to components of the subsystems in summary bar chart form. Table XI tabulates numerical values and lists primary parameters contributing to these results.

In addition to the elimination of hydraulic system heat loads and reduced pumping heat loads, significantly reduced heat loads from the lubrication system and ambient heating of fuel lines are shown in figure 67 for the STJ346A. Reduced lubrication system heat generation results from (1) elimination of one bearing compartment because of the shorter engine design (fewer stages resulting from increases in turbine temperature and stage loading), (2) design of bearing compartments using advanced technology to minimize conductive heat paths, to insulate from environmental heating and to reduce gas path leakage, (3) use of advanced insulation techniques for lubricant transfer lines, gearbox and other components, and (4) reduction in exposed area because of the more compact arrangement for the shorter engine. The shorter and more compact STJ346A engine also contributes to reduced ambient heating of fuel due to reduced surface area for fuel lines that are exposed to the hot environment. Advanced insulation techniques for fuel manifolds and special attention to routing of internal fuel lines to fuel distribution nozzles in the combustors further minimizes environmental heating of fuel for the STJ346A.

The total effect of these differences is an estimated total heat load to be absorbed by the fuel in the STJ346A engine of approximately 1/3 that of the J58. This results in the significantly lower fuel and lubricant temperatures for the STJ346A, based on special attention in design to minimize heat loads and to apply thermal management technology that was developed in the 15 years subsequent to the design of the J58. The study indicates that careful attention to thermal design, supported by adequate experimental work, should result in new engine designs that could use lower cost fuel for similar cruise Mach numbers or could operate at higher Mach number using the same fuel.

Figure 68 compares the J58 and STJ346A fuel/oil cooler operating temperatures, flowrates, and heat transfer requirements. The lower oil system heat transfer requirement and lower fuel/oil cooler inlet fuel temperature account for the reduced thermal stability lubricant requirement for the STJ346A in comparison with current J58 experience.

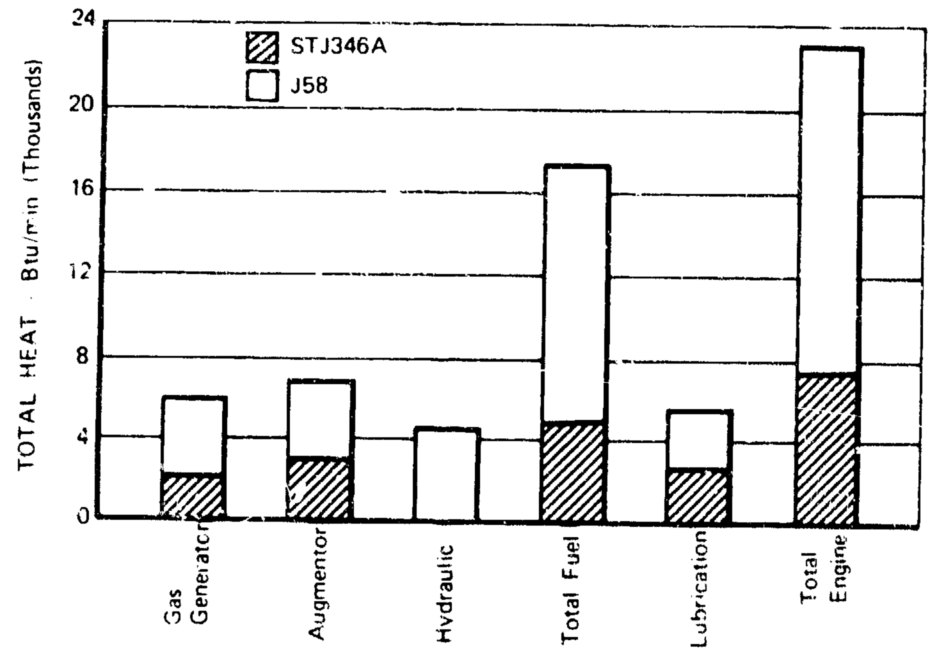


Figure 66. Comparison of STJ346A and J58 Engine Heat By Major Subsystems

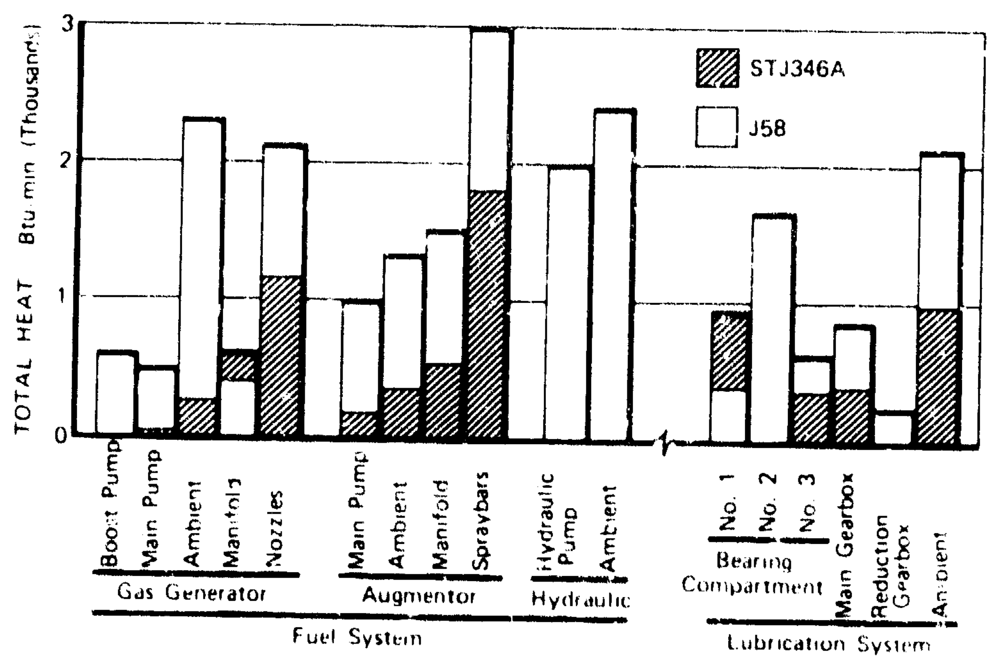


Figure 67. Comparison of STJ346A and J58 Engine Heat By Components

Table XI. J58 and STJ346A Engine Heat Summary - Btu/min

	J58	Comments	STJ346A	Comments
Engine Total	23,148		7,960	
A. Fuel System Total	17,298		5,257	
1. Gas Generator Total	6,013		2,057	
Boost Pump	600	Efficiency 10% ΔP 130 psi		Not Applicable.
Main Pump	525	Efficiency 8.5% ΔP 120 psi	47	Efficiency 62% ΔP 190 psi
Ambient	2,325	Area 21 ft^2	560	Area 4 ft^2
Manifold Total	435	Area 3.4 ft^2	290	Area 8.8 ft^2
Nozzles Total	2,128	Exposed Can - Annular Clusters	1,160	Individual Supports
2. Augmentor Total	6,885		3,200	
Pump	750	Efficiency 20% ΔP 250 psi	195	Efficiency 33% ΔP 126 psi
Ambient	1,580		750	Area 4.9 ft^2
Manifold Total	1,530	Area 12 ft^2	450	Area 4.0 ft^2
Spraybars Total	3,025	Submerged Manifold Sprayrings	2,000	20 Radial Supports
3. Hydraulic Fuel Total	4,400			Not Applicable.
Pump	2,000	Efficiency 45% ΔP 2,500 psi		
Ambient	2,400	Area 26 ft^2		
B. Lubricant System Total	5,850		2,703	
1. Bearing Compartments	2,652		1,314	
No. 1 (Front)	400	Roller Bearing	927	Single Ball Bearing, 1 Seal, Tower Shaft
No. 2 (Intermediate)	1,652	Duplex Ball Bearing, 2 Seals, Tower Shaft		Not Applicable.
No. 3 (Rear)	600	Roller Bearing	387	Roller Bearing
2. Gearbox	848		421	
3. Intermediate G/B	230			Not Applicable.
4. Ambient	2,120	Area 30 ft^2	968	Area 11 ft^2

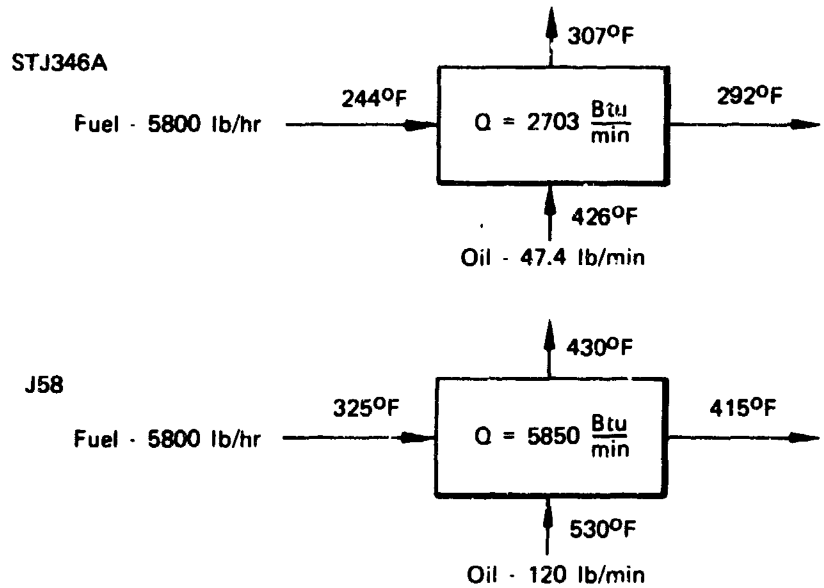


Figure 68. STJ346A and J58 Fuel/Oil Heat Exchanger Comparison

5. Supplemental Fuel Cooling

Thermal analyses indicated that the heat sink available from the thermal capacity of the STJ346A engine fuel flow was greater than that needed to (1) cool the lubricant and (2) accommodate other heat loads for the baseline fuel system and baseline mission. Based on heating fuel flow to the extent that main burner fuel nozzle temperature corresponds to the fuel thermal stability limit, figure 69 shows the fuel heat sink that would be available for other purposes. Several possibilities to use this available heat sink were investigated and found to offer insufficient benefits to offset their disadvantages, as discussed in the following paragraphs. Additionally, this heat sink would not be available for transient maneuvers and flight envelope extremes.

a. Precooling Turbine Cooling Air

To improve the performance of the STJ346A engine, a study was made of the potential to reduce turbine cooling airflow by precooling the air with the excess heat sink available in the fuel consumed by the engine. Maximum potential benefits were estimated using JP-7, assuming no system losses or component inefficiencies. A more detailed analysis would be expected to show smaller fuel consumption advantages; these would be offset by component weights and losses.

Figure 70 shows a sketch of a system to bleed turbine cooling air from the compressor discharge, precool the air with a fuel/air heat exchanger, and distribute the air to vanes, rub strips, and rotating parts. To prevent overtemperaturing the fuel when power is reduced, an air bypass of the heat exchanger is provided. The incorporation of this fuel/air heat exchanger in the STJ346A fuel and lubrication system schematic is shown in figure 71. It is downstream of the fuel/oil cooler, so that only fuel distribution manifolds and nozzles will be influenced by the increased fuel temperatures. Other system locations were considered, but they would return part of the added fuel system heat load to the airframe and/or increase fuel temperature to the oil cooler and raise the overall lubricant system temperature.

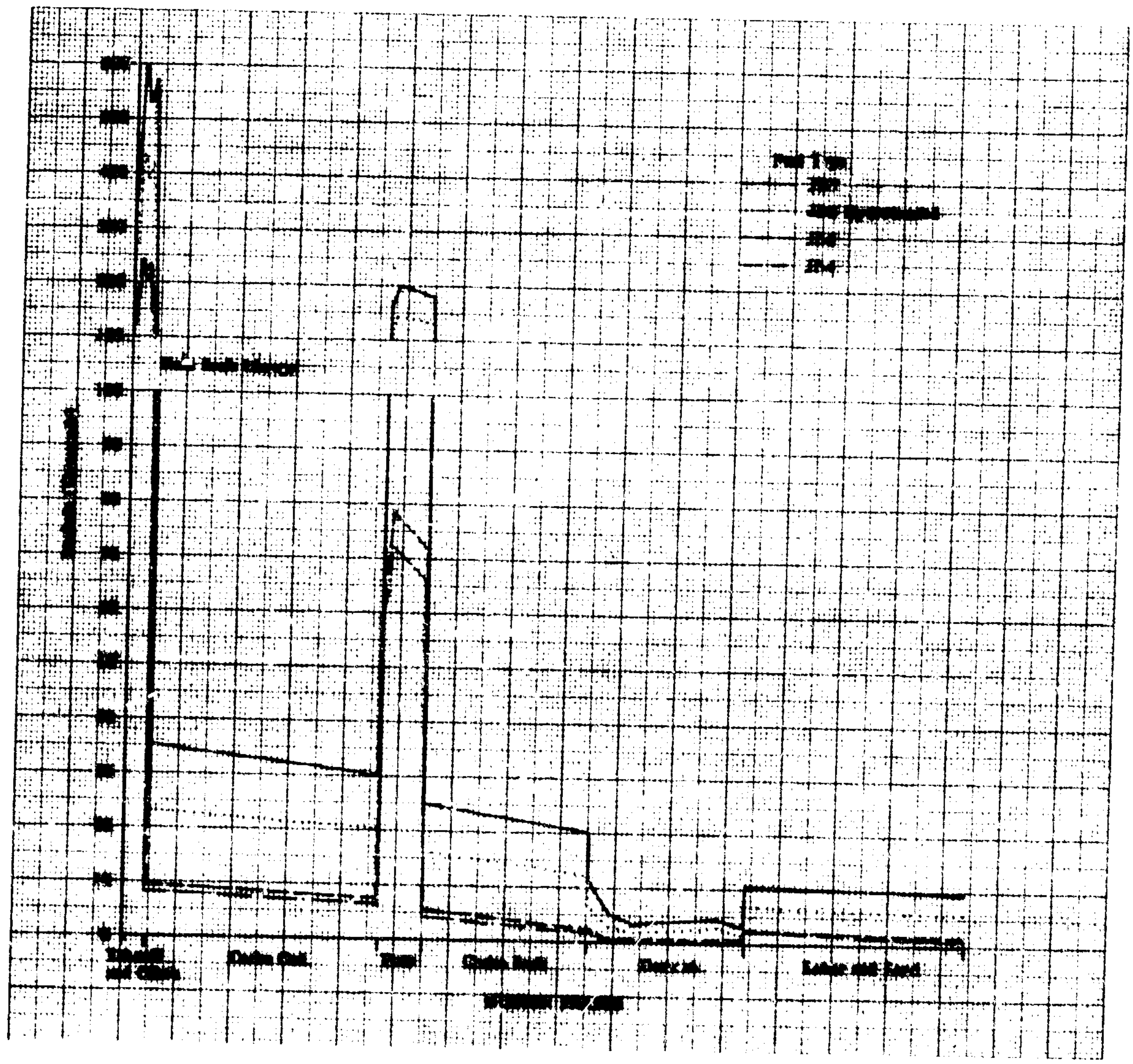


Figure 69. Potential Heat Sink Available for STJ346A Utilization During the Mission

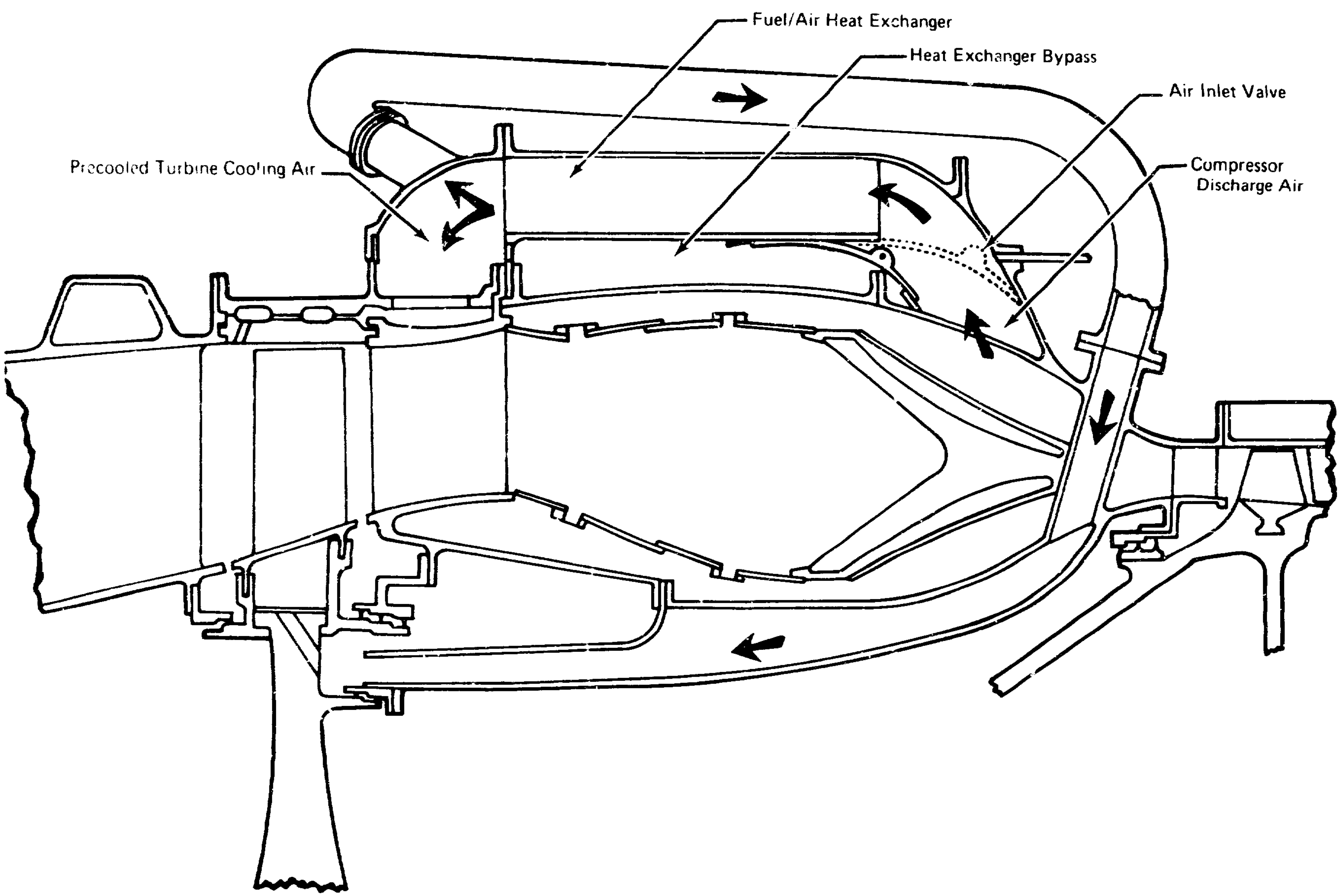


Figure 70. STJ346A Schematic for Precooling Turbine Air With a Fuel/Air Heat Exchanger

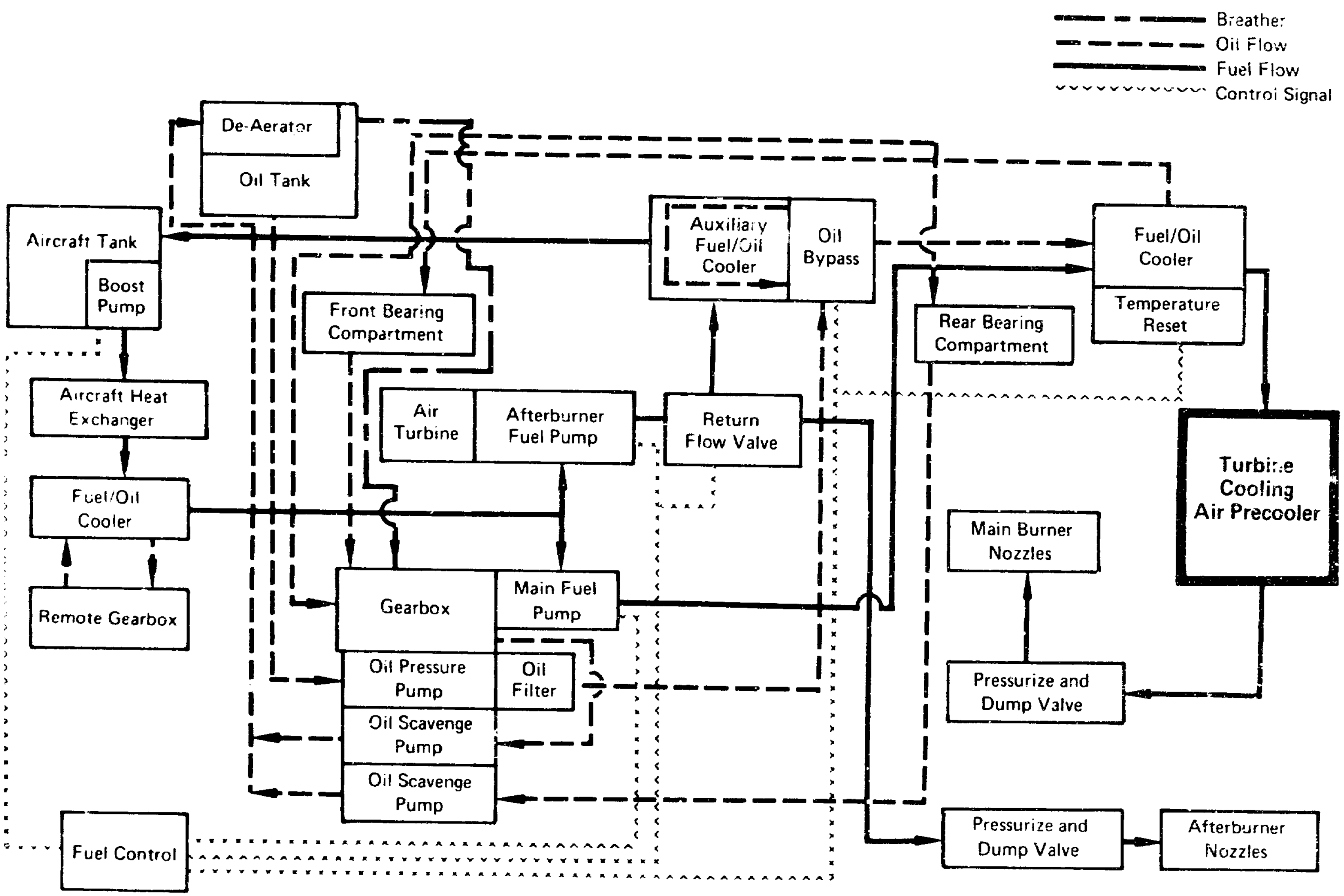


Figure 71. Incorporation of the Turbine Cooling Air Precooler in the STJ346A Engine Fuel and Lubrication Baseline System

The STJ346A operating conditions and engine parameters established turbine cooling requirements. From the start of the mission to the end of the cruise back the turbojet is at maximum turbine inlet temperature, with afterburner augmentation used during the takeoff, climb, and turn. The following mission points on figures 19 and 20 were analyzed to establish a design point:

- The augmented climb intercept with Mach 3+ - Point No. 18
- The start of the cruise out - Point No. 22
- The end of the cruise out - Point No. 24
- The start of the augmented turn - Point No. 25
- The end of the cruise back - Point No. 32

During the STJ346A mission, the turbine cooling airflow varied, as shown in figure 72. The reduction in turbine cooling air and the corresponding temperatures to which it could be cooled are shown in figure 73. The reduced turbine cooling air temperatures, shown for each mission point, include the compounding effect of less turbine cooling air being required at the lower temperature; therefore, a constant heat sink rate can cool the lower weight flow of air to a lower temperature. The allowable percentage reduction in turbine cooling airflow vs the temperature of the precooled air is shown for the STJ346A turbine in figure 74. From these data, fuel temperatures, heat sink capabilities, air temperatures, and potential turbine cooling air temperature reductions can be estimated and are provided on table XII for the mission points analyzed. The precooling of turbine cooling air is limited to 1775°F at the end of cruise back. Figure 74 shows the total percentage of TCA reduced from 9% to 7.25% at this temperature.

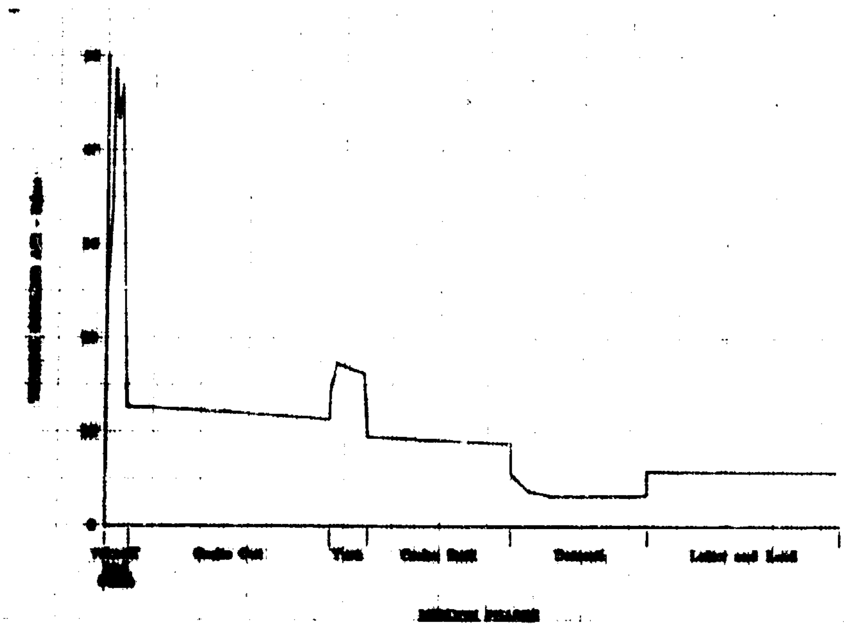


Figure 72. Turbine Cooling Airflow Required for the STJ346A Mission

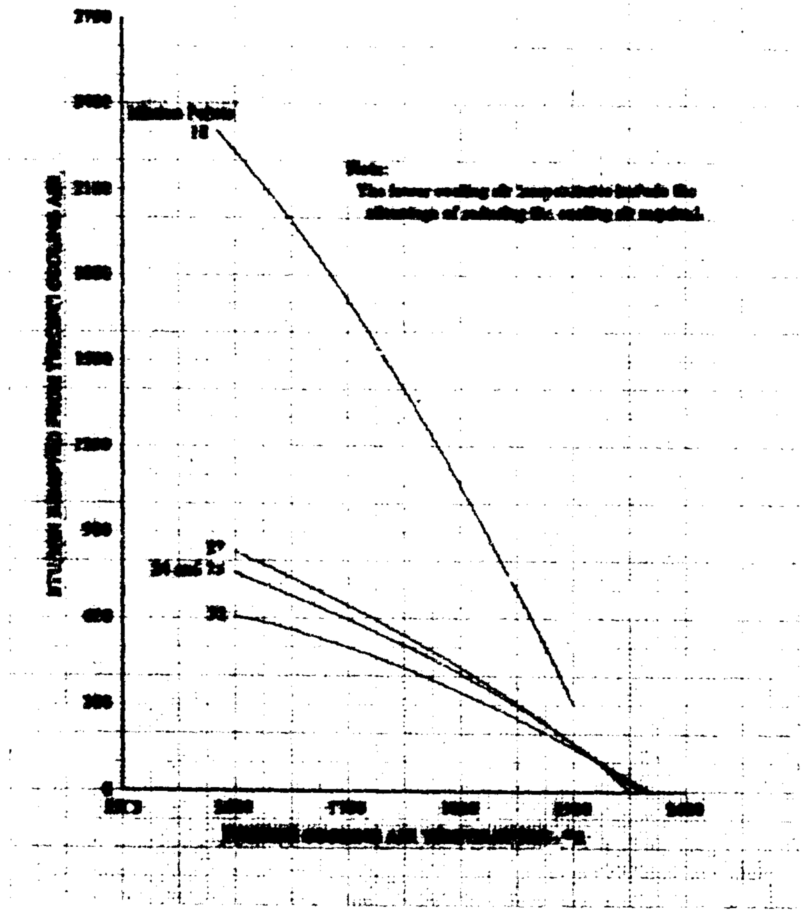


Figure 73. Heat Sink Rate Required for Precooling the STJ346A Turbine Cooling Air

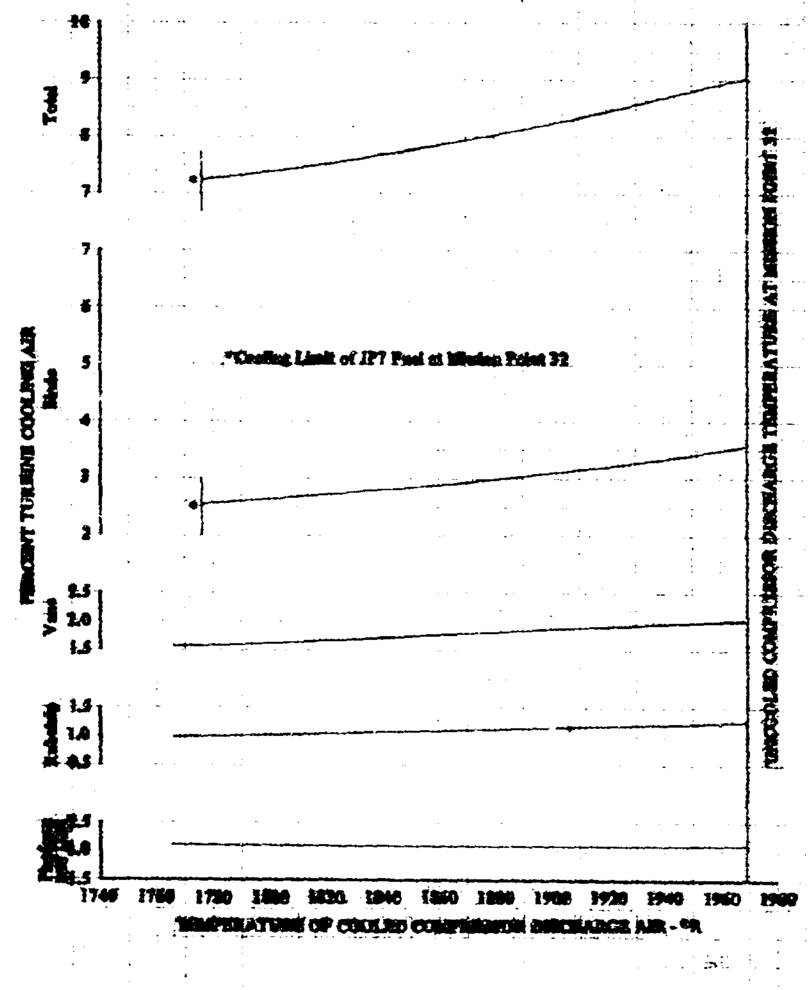


Figure 74. Precooling Reduces the Required STJ346A Turbine Cooling Air

Table XII. STJ346A Mission Point Analysis of Potential Turbine Cooling Air Temperature Reductions

Mission Point Number	Allowable Air Cooler Fuel ΔT, °F	Turbojet, W_f-lb/sec	Available Heat Sink, Btu/sec	Compressor Exit Temperature, °F	Precooled TCA, °F
18	463	7.67	2310	1931	1585
22	362	2.65	659	1950	1695
24	348	2.38	574	1958	1715
25	417	2.37	659	1958	1665
*32	290	1.83	378	1969	1776

*Limiting mission point for reduction of turbine cooling air

The Mach 3+ STJ346A mission was run on the computer program used for the initial propulsion system selection to compare total mission fuel requirements with 9% and 7.25% turbine cooling air inputs to the engine performance deck. A fuel savings of 164 lb was computed, which was about 0.5% of the total fuel load. The air cooler would have to be sized to pass the highest flow of 48 lb/sec shown in figure 72, and fuel and air piping would be needed. These components would increase engine weight an estimated 90 lb, add environmental heat transfer surfaces, increase component losses, and add operating and mechanical complexities. Considering the small net weight savings, the concept to precool turbine cooling air with fuel did not appear to be attractive.

b. Direct Fuel-Cooled Turbine

Since weight and complexity of an intermediate heat exchanger is avoided, several concepts for direct fuel cooling turbine components were considered. These included cooling vanes and rub strip segments, as shown in figures 75 and 76.

Reference was made to NASA Technical Note, NASA TN D-4491, "Considerations of Turbine Cooling Systems for Mach 3 Flight," to determine the amount of heat that must be removed from the 1st-stage vane. Figure 2a of the NASA Technical Note provided a curve for heat sink capacity required for 1st-stage vanes. The heat sink scale for this curve was modified for the smaller STJ346A study engine airflow, as shown in figure 77. For a maximum metal temperature of 2230°F and a hot spot gas temperature of 3000°F, the vanes required a heat sink of 480 Btu/sec. The available fuel heat sink at this time (mission point No. 32) was 378 Btu/sec. From this, it was concluded that direct fuel cooling of the 1st-stage vanes could not be totally substituted for the vane portion of the turbine cooling air requirements.

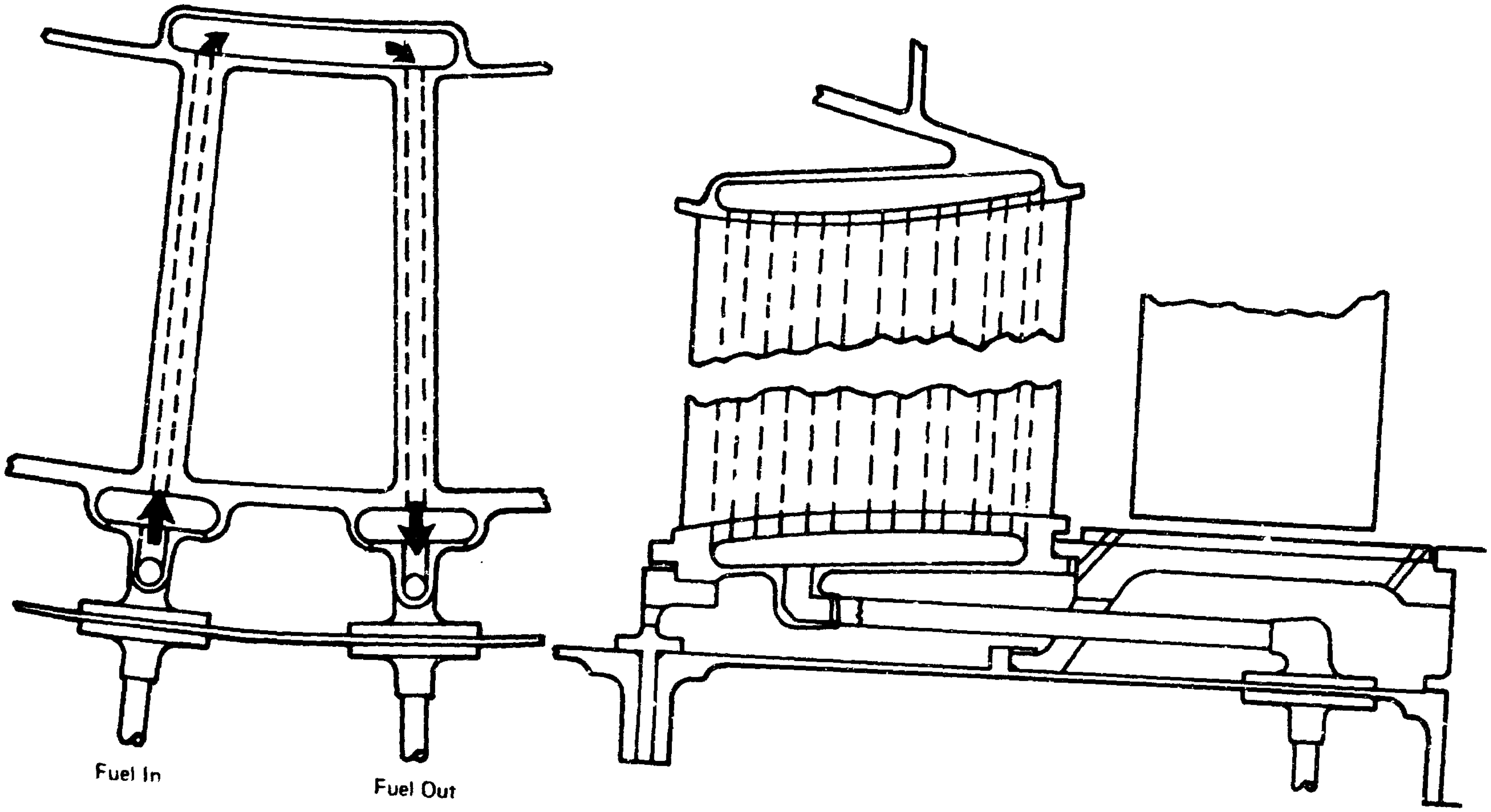


Figure 75. Concept for Direct Fuel Cooling STJ346A Turbine Vanes

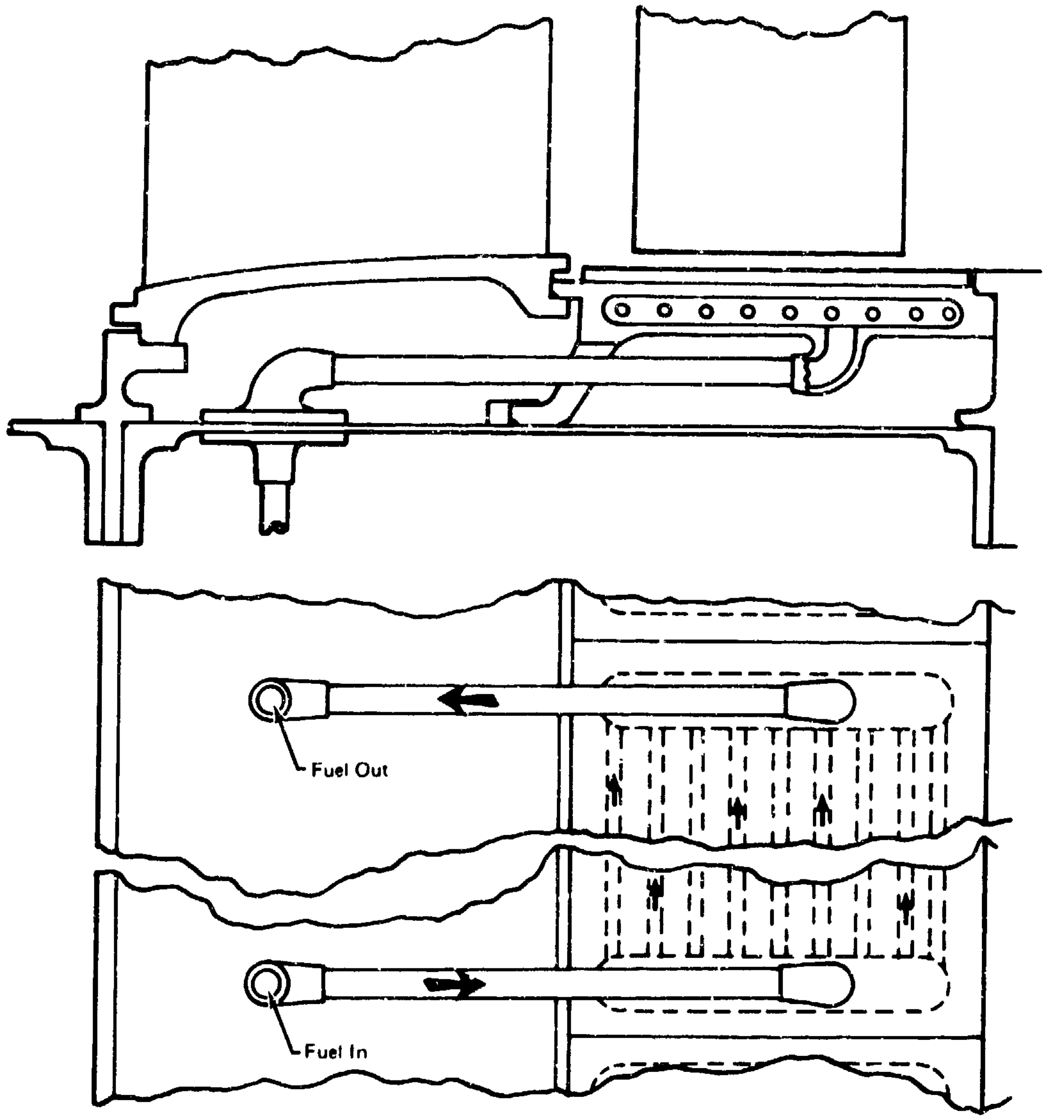


Figure 76. Concept for Direct Fuel Cooling STJ346A Turbine Rub Strip Segments

The distribution of turbine cooling air in figure 74 shows that turbine rub strip segments require two-thirds of the cooling required by the vanes. On this basis, the rub strip segments would require a heat sink of 320 Btu/sec within the available 378 Btu/sec. Direct cooling substitution would eliminate the 1.3% rub strip cooling air. This saving of 1.3% of engine airflow by direct fuel cooling of one turbine component provides less gain than the 1.75% airflow saving previously shown by precooling turbine cooling air. Because of the potential hazards and the small mission advantage shown for a better system, direct fuel cooling investigations were discontinued.

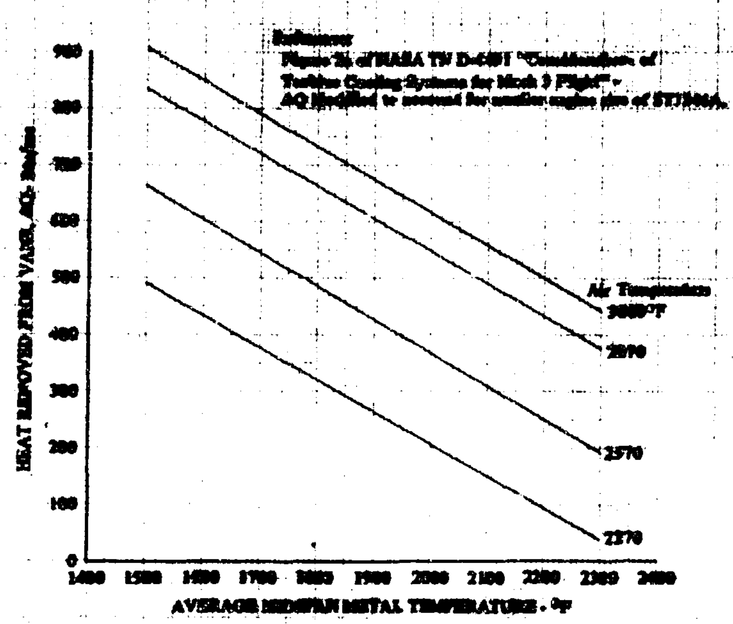


Figure 77. Turbine Vane Cooling Requirements for the STJ346A

c. Airframe Heat Sink Utilization

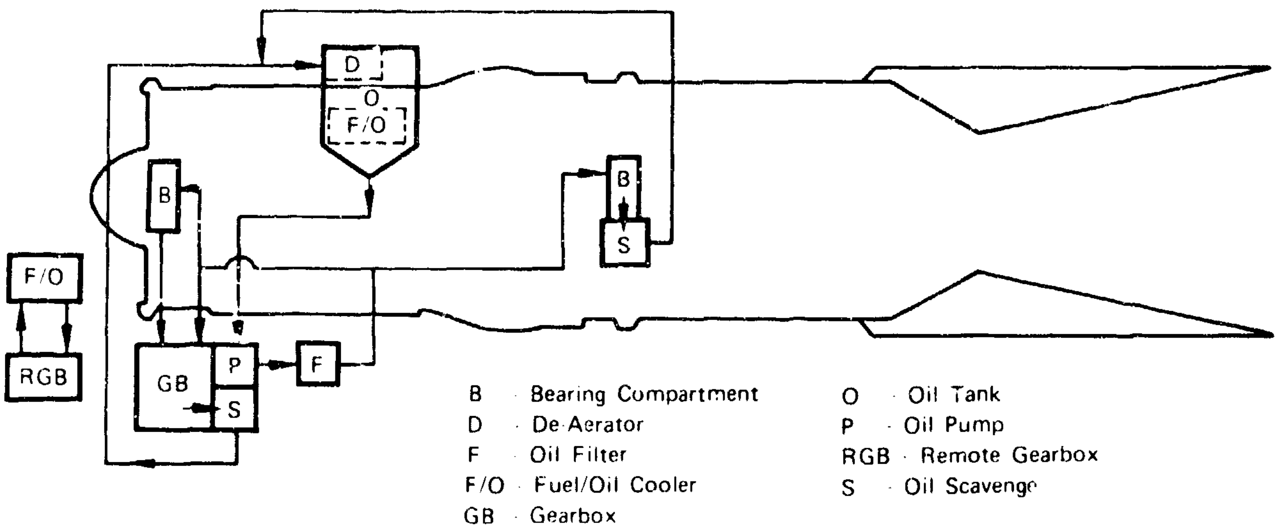
A review of this study contract was made with McDonnell Douglas to discuss possible airframe and engine trade studies associated with the fuel and lubrication systems. The availability of excess fuel heat sink during the mission generated an interest in the possibility of its use by the airframe. However, efforts to find aircraft benefits from higher allowable interface temperatures were not successful. Removal of tank insulation that would result in greater environmental heating of fuel did not appear beneficial because structural weight would be increased to provide adequate strength at the higher temperatures. The effectiveness of environmental control systems would benefit from lower fuel temperatures but more heat sink that could be made available at higher fuel temperatures would have no apparent benefit.

6. Alternate Fuel and Lubrication Concepts

Examples of an alternate lubrication system and an alternate fuel system that were considered are included in this subsection. Other alternatives could be considered, including gearboxless designs that were used for the higher Mn turboramjet engine. However, the goal was to select near-term technology for the lower Mn afterburning turbojet as long as these selections satisfied operating requirements.

The major feature of the alternate lubrication system shown in figure 78 is tank storage of lubricant at minimum system bulk temperature. Potential problems that would require special designs to make this a viable system are

satisfactory filtration and deaeration of lubricant before passing it through the fuel/oil cooler and satisfactory oil side heat transfer coefficients consistent with allowable system pressure losses. The major difference from the baseline system is that lubricant is cooled upstream rather than downstream of the main lubricant pump. The fuel/oil cooler is schematically shown to be integral with the tank, but it could also be physically located upstream of the storage tank if deaeration could be accomplished adequately and with low pressure loss upstream of the cooler.



Advantages

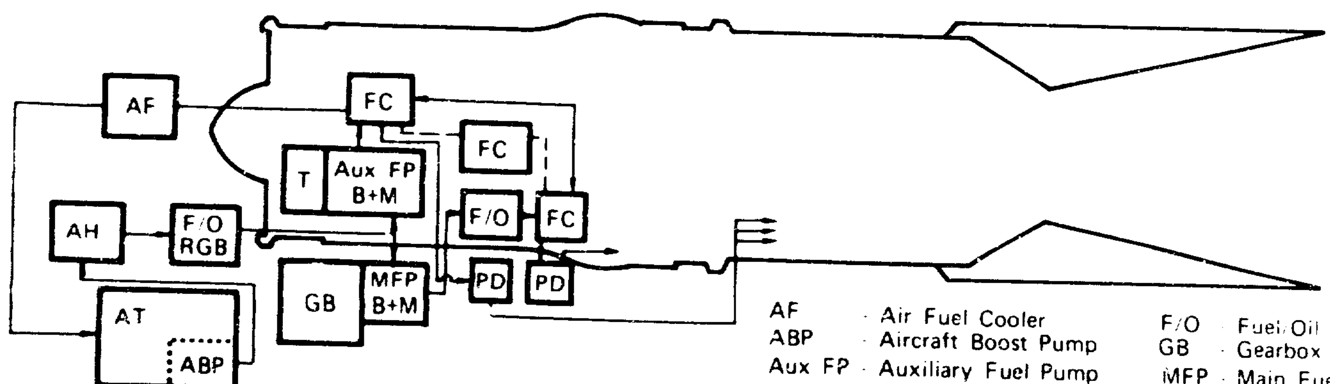
- Lower bulk oil storage temperature

Disadvantages

- Potential oil side heat transfer problem for low ΔP on pump suction
- Unfiltered oil into the fuel/oil cooler

Figure 78. STJ346A Alternate Cold Tank Lubrication System

Figure 79 shows an alternate fuel system concept that was suggested by the total fuel flow demand characteristics for the STJ346A afterburning turbojet engine during the typical interceptor mission. The turbojet gas generator has a maximum fuel flow demand that exceeds the sum of gas generator and afterburner fuel flow for all but the initial 2.5 min of the mission. Except for this 2.5-min period, a single pump could provide the required 60:1 flow turndown ratio at maximum fuel pressure of about 700 psi. By providing total gas generator and afterburner fuel flow with a single pump, the pump is generally operating at higher efficiency and thus minimizes the undesirable temperature rise across the pump. This concept is employed in the system shown in figure 79. The main fuel pump consists of a gearbox-driven boost pump and variable displacement vane pump.



AF	Air Fuel Cooler
ABP	Aircraft Boost Pump
Aux FP	Auxiliary Fuel Pump
AH	Aircraft Heat Exchanger
AT	Aircraft Tank
B+M	Boost and Main
FC	Fuel Control
F/O	Fuel/Oil Cooler
GB	Gearbox
MFP	Main Fuel Pump
PD	Pressurize and Dump Valve
RGB	Remote Gearbox
T	Air Turbine

Advantages

- Main pump usually operating at efficient, high flow conditions
- Auxiliary pump only required for max initial climb power
- Air cooling of recirculated fuel during subsonic loiter
- Adaptable to use of auxiliary pump as backup for main pump

Disadvantages

- Control system complexity
- Auxiliary pump must maintain cooling flow when output is not required

Figure 79. STJ346A Alternate Auxiliary Pump Fuel System

The auxiliary pump is shown as a turbine-driven pump but could be a simple direct-driven pump with flow bypass as it only operates at high fuel flow conditions when available fuel heat sink is not critical. In the event that required aircraft heat exchanger and engine lubrication coolers need more cooling than could be supplied by engine fuel flow, a recirculation loop to aircraft tanks is included. Because this situation would most likely occur at low-speed aircraft descent when ram air cooling is feasible, an air/fuel cooler is located in the recirculation loop. This feature would minimize heat addition to the fuel stored in aircraft tanks at the critical time when fuel has already been heated throughout the completed mission and the remaining quantity of fuel is low. Although this system appears to have significant advantages, these have not been quantitatively evaluated and the required complexity of a fuel control system to split flow properly between the gas generator and afterburner was judged to be sufficient to select the baseline concept. Since the baseline system design proved to be thermally compatible with selected fuels and lubricants, alternate basic concepts were evaluated no further.

F. FUEL AND LUBRICANT INFLUENCES

The primary influences of fuels and lubricants on the STJ346A afterburning turbojet are constraints in design and operation because of operating temperature limitations of the fluids. Thermal stability temperature limits, hot spot stability temperature, autoignition temperature, vapor pressure at temperature, viscosity, by-products formed by decomposition, catalytic effect of construction materials, and corrosive effects on construction materials influence the system design, operating flexibility, reliability, safety, maintainability and costs (development, production, and operating). The primary problem for the high Mach application is to determine satisfactory trades between availability of fluids, the required fuel and lubricant characteristics, and compromises to the design of the complete engine/aircraft/operational/support system. In designing a new engine, the approach would be to initially design using the best available technology consistent with minimum compromise in cost, risk, weight, and performance and determine if the resulting design were consistent with available fuels and lubricants. Negative results would require trading design compromises with problems in developing new fuels and lubricants or consideration of existing cryogenic fuels that could solve the heat sink problem, but would introduce a new and more costly logistics system. For the STJ346A engine, hydrotreated 500°F JP-5 fuel and MIL-L-27502 lubricant had minimum bulk temperature capabilities to satisfy all operating conditions. Sophisticated design concepts were necessary to minimize fuel and lubricant temperature, but all were considered to be state-of-the-art. Supplementary cooling systems such as ram air/oil (or fuel) coolers or water vaporization cooling were not needed. Each pound added to STJ346A engine weight would have resulted in 5.6-lb increase in aircraft GTOW as determined in analyses of the baseline mission.

1. STJ346A Fuel Selection

The initial screening criteria was that the maximum bulk fuel operating temperature in the system be compatible with fuel thermal stability limits. Subsequently it was determined that other characteristics were also suitable. The thermal stability temperature limits of the selected fuels that were coordinated with the Air Force Project Engineer were as shown in table XIII; Appendix IV lists properties of these fuels.

Table XIII. Fuel Thermal Stability

Fuel	Bulk Temperature Limit, °F
JP-4	325
JP-8	325
JP-5	350
Hydrotreated JP-5	500
JP-7	600

Maximum fuel temperatures were estimated for the various alternate operating conditions that could be postulated. Based on the baseline definition of fuel tank temperature, aircraft heat load, and mission flight conditions, the maximum STJ346A fuel temperature was estimated to be 325°F (figure 21). Cruise conditions at alternate aircraft/engine interface temperatures showed maximum fuel temperatures of 225°F for 150°F interface, 310°F for 250°F interface, and 395°F for 350°F interface temperature (figure 27). Based on use of fuel recirculation (return of fuel from engine to aircraft tanks) and aircraft tank fuel temperature up to 250°F, figures 38 and 39 show that it should be possible to limit maximum transient fuel temperature to 400°F for transient maneuvers. Provision for steady-state flight at any point in a realistic flight envelope could require fuel temperature capability up to 500°F, as shown in table VI, based on no supplementary cooling and operation on the left-hand side of the flight envelope. Accordingly, hydrotreated JP-5 would have the minimum bulk temperature capability to satisfy all the above postulated operating requirements. An alternate approach could be considered that would employ an air/fuel cooler for use at steady-state flight conditions having low ram temperature and with low fuel flow to limit the maximum fuel temperature to 400°F. This could be considered if JP-5 could be treated to achieve 400°F thermal stability at significantly lower cost than for 500°F. There would be a trade against increased aircraft unit cost for an estimated 0.2% increase in gross takeoff weight to provide the supplementary ram air cooling system.

Higher density of normal JP-5 compared to hydrotreated JP-5 could be of sufficient advantage in volume-limited aircraft to work on needed improvements in thermal stability through deoxygenation, tank inerting, antioxidant and/or various chemical additives. The tendency of JP-5 to form insoluble compounds with excessive residence time at 250 to 300°F temperatures is a weakness that could require correction due to the need for recirculation and anticipated duration of tank soak at elevated temperature for postmission loiter, landing, and ground hold. PSJ-162 fuel, pg 245, Appendix IV, offers an alternate solution.

The fuel systems for transport and supply of fuel for the STJ346A should contain no copper, brass, bronze, nor cadmium alloys to avoid degradation of fuel properties from metallic migration.

JP-4 or similar high volatility fuel would not be appropriate regardless of improved thermal stability because of the need for heavy pressurized fuel tanks, potentially high evaporation loss, and fire hazard from low boiling components of JP-4. JP-8 would be excluded on a similar basis because the fuel specification allows significant concentration of low boiling pressure compounds.

2. STJ346A Lubricant Selection

The initial criteria for selection of a lubricant for the STJ346A engine was that it be compatible with maximum bulk oil temperature predicted for the STJ346A lubrication system. Candidate lubricants under this study and their corresponding thermal stability (bulk oil temperature) limits, as coordinated with the Air Force Project Engineer, are shown in table XIV; Appendix IV lists the properties of these lubricants.

Table XIV. Lubricant Thermal Stability

Lubricant	Bulk Temperature Limit, °F
MIL-L-27502	425
Hypothetical Ester	500
Polyphenyl Ether	575
Perfluorcnated Polyether	650

Based on the baseline definition of fuel temperature profiles for mission flight conditions, the maximum STJ346A lubricant temperature was estimated to be 345°F (figure 22). Cruise flight conditions at alternate (from the baseline mission) aircraft/engine interface temperatures of 150, 250, and 350°F showed corresponding maximum lubricant bulk temperatures of 260, 330, and 425°F (figure 28). Transient maneuver conditions of low fuel flow at maximum ram temperature flight conditions had little effect on the lubrication system due to the thermal lag from its heat capacity; and fuel recirculation was shown (figures 38 and 39) to limit fuel temperature, which provides cooling to further limit high lubricant temperature transients. Steady-state operation at corners of the flight envelope for 350°F interface (table IX) results in the estimated maximum bulk lubricant temperature of 425°F. Therefore, MIL-L-27502 lubricant would have the minimum capabilities to satisfy the estimated bulk oil temperatures for the STJ346A.

Of the other criteria the lubricant must satisfy, the autoignition temperature (AIT) presents a potential problem. Tests show the 785°F AIT of MIL-L-27502 at ambient pressure can be depressed up to 200°F at the pressurized conditions inside the bearing compartment, presenting a potential ignition problem in conjunction with hot spot temperatures that might exceed the estimated 550°F and potential seal leakage of air at temperatures above 1200°F. However, this potential problem has not been encountered in engine operating experience at similar conditions. Furthermore, it would be anticipated that design approaches and/or lubricant AIT improvement could solve this concern; alternatively, polyphenyl ether lubricant would be a solution for compatible AIT. Many other factors must be considered in selecting the lubricant. These support the selection of an ester similar to MIL-L-27502.

In comparison, if polyphenyl ether lubricant were needed for improved autoignition and thermal stability characteristics, the low temperature viscosity and load-bearing capacity would be relative disadvantages. However, polyphenyl ether would perform satisfactorily at higher temperatures than MIL-L-27502, and corrective measures such as dilution with MIL-T-7003 trichloroethylene can allow low temperature engine starting.

Current gear lubrication theory is insufficient for accurate prediction of maximum allowable gear loading in design of the STJ346A engine gearbox using the candidate lubricants at the estimated operating conditions. Elastic deformation of gears under load, the viscosity variation with gear contact pressure at operating temperatures, and comparison of the lubricant film thickness with surface roughness of gear surfaces should be considered in design of these gears for adequate life and minimum weight. Elastohydrodynamics (EHD) theory should be further developed in conjunction with experimental data to develop the needed gear design system that includes accurate consideration of lubricant characteristics in establishing allowable gear loading.

SECTION IV

HIGH MACH NUMBER ENGINE STUDY

A. ENGINE SELECTION

The primary goal of the high Mach number engine study was to evaluate the influence of fuels and lubricants on an Air Force Mach 4+ interceptor for the 1980's. The high ram air temperatures and pressures necessitate ramjet propulsion during cruise due to turbine engine materials limitations and result in the ramjet cycle being more efficient for cruise than a turbojet/turbofan. Accordingly, several turbine engine/ramjet multicycle engines were compared to select one as a basis for design and analysis of the fuel and lubrication system. Data prepared by McDonnell Douglas Aircraft Company under USAF Contract F33615-69-C-1388, Comparative Propulsion System Concepts, were the basis for mission and aircraft characteristics (described in Volume I). The mission consisted of a required high rate of acceleration to cruise, Mach 4+ cruise, combat maneuvers, cruise back at Mach 4+, descent, and brief loiter before landing. Aircraft and mission characteristics were used in an FRDC mission analyses computer deck to solve the engine cycle that minimized aircraft gross takeoff weight.

The candidate FRDC study engines were the STRJ334A-S turboramjet, STFRJ335 turbofanramjet, and STFRJ368 turbofanramjet. Comparative gross takeoff weights were generated using an aircraft and engine sizing procedure that was obtained from the FRDC APSI studies (Contract F33657-69-C-0270). A block diagram of this computerized procedure is shown in figure 80. Engine performance data were generated for each of the candidate engines at 40 altitude and Mach number points. These points included the mission phases of takeoff, climb, cruise, combat, and loiter.

The aircraft gross takeoff weight to meet the mission requirements was influenced by the ratio of the ramjet design airflow to the core design airflow for each of the candidate study engines, as shown in figure 81. The STRJ334A-S provides the lightest weight aircraft and the least sensitivity to variations in the ramjet to core airflow ratio. The initial criteria for establishing the gross takeoff weight were the climb time and intercept requirements. For the STRJ334A-S and STFRJ368 engines, the ramjet power required for the mission turn also became a determining factor. The turn requires selection of a larger engine size than would otherwise provide minimum aircraft weight along the dashed portion of the curves in figure 81. The STFRJ335 was not able to reach a competitive gross takeoff weight because of matching limitations of the single-spool, turbofanramjet configuration.

B. STRJ334B TURBORAMJET DESCRIPTION

Subsequent to the selection of the STRJ334A-S turboramjet engine the design was reviewed and updated to incorporate features from recent studies of advanced multistage compressors, high performance bearings, and engine exhaust nozzles. Engine cycle performance and total weight were not significantly affected by the changes to these components. The revised configuration was designated the STRJ334B. The engine is shown in figure 82 and incorporates bearing compartment, fuel distribution, and exhaust nozzle revisions that were developed from results of this study.

The STRJ334B is a multicycle turboramjet designed for 1985 interceptor applications at speeds above Mach 4 using JP fuel. The core turbojet engine operates from takeoff through a flight speed of approximately Mach 3. The wraparound ramjet operates from Mach 1 to 4+. The unique characteristic of this engine is its capability for either turbojet, ramjet, or dual mode of operation from Mach 1 to 3+, illustrated in figure 83. Two of these engines of approximately 35,000-lb sea level takeoff thrust size (turbojet core) were used in the application studied. Ramjet cruise-to-turbojet takeoff corrected airflow ratio is 0.25.

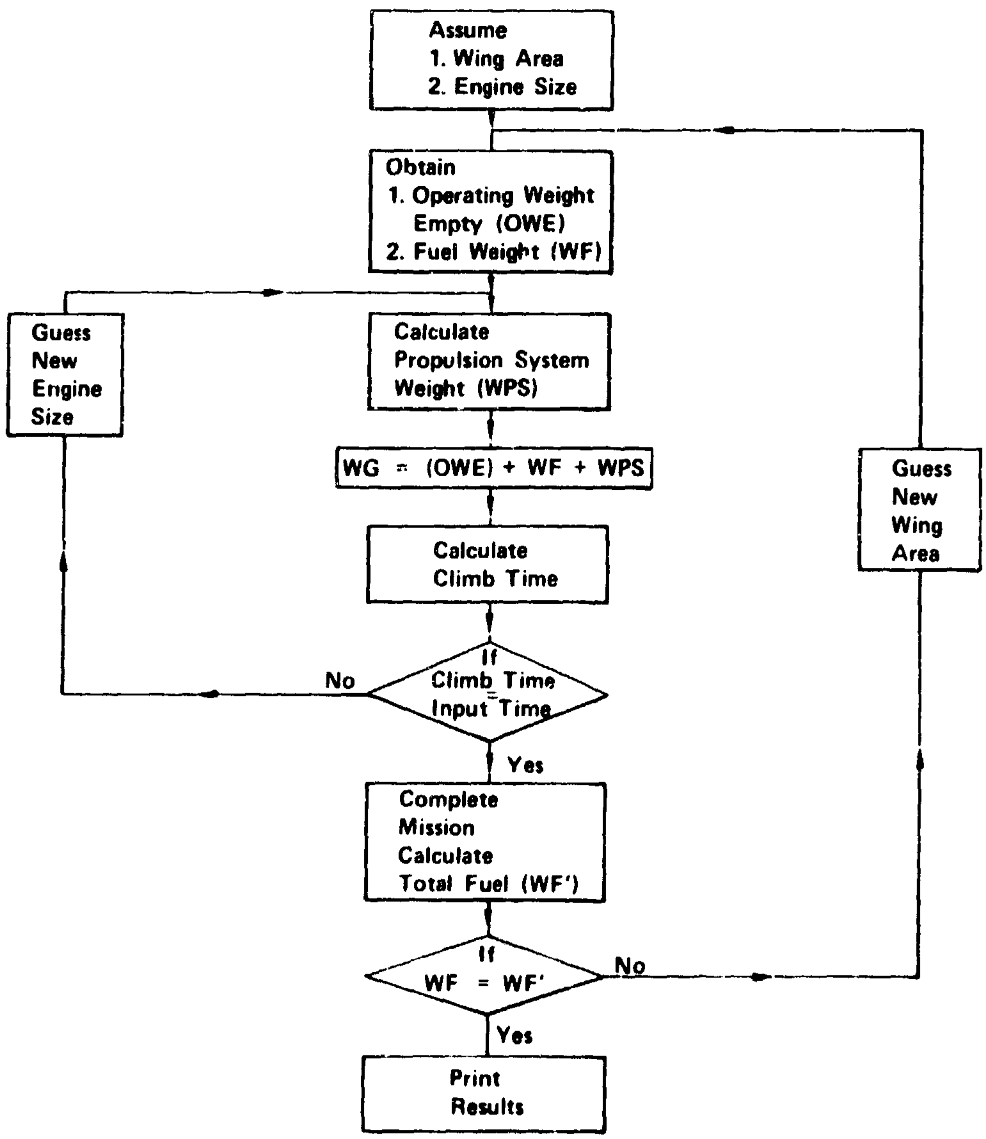


Figure 80. AMI Aircraft/Engine Sizing Procedure

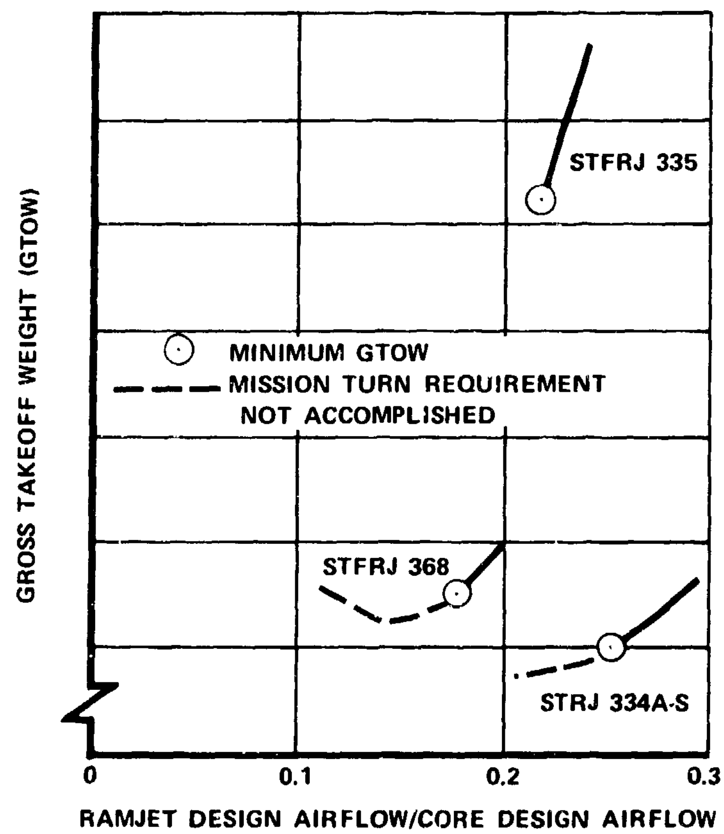
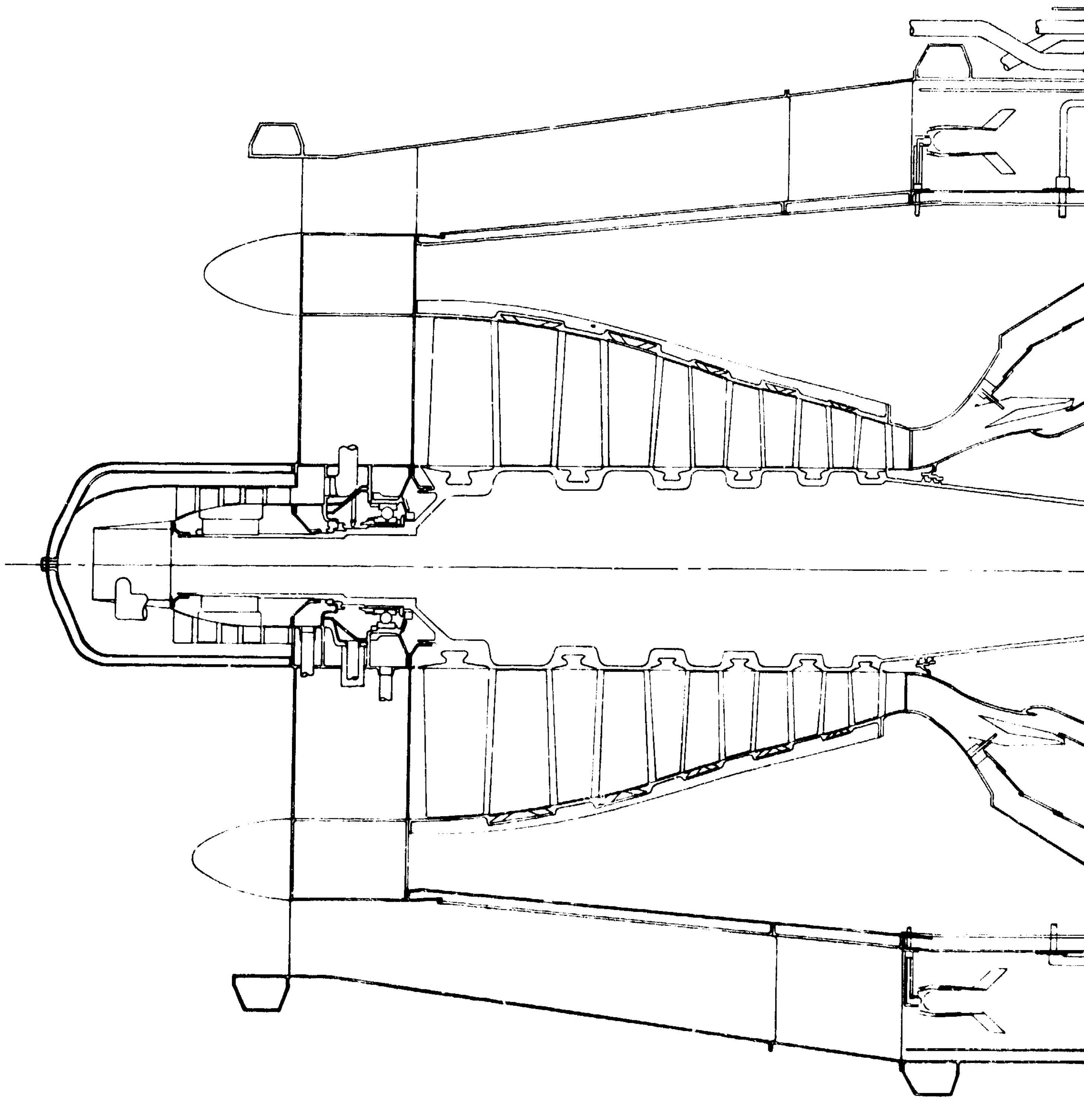


Figure 81. Gross Takeoff Weight Required for High Mn Candidate Engines

The engine has a single-spool, six-stage, 12:1 pressure ratio compressor with a constant inner diameter. This flowpath provides a cavity for sheltered placement of fuel and lubricant components between the core engine and the ramjet.

The burner is stoichiometric, with a heat release rate of 10 million Btu/hr-ft^3. Stoichiometric operation in the main burner eliminates a requirement for afterburning, thus minimizing engine length, weight, and volume. A one-stage turbine drives the compressor, which has a drum rotor that prevents leakage and helps to isolate internal critical components from the heat of the main gas path. A variable-area turbojet exhaust nozzle permits matching to stoichiometric operation over the entire climb path. The ramjet is housed in a wraparound duct surrounding the core engine. The ramjet does not operate below Mach 1; therefore, below this Mach number, air is shut off from the duct by closing the ramjet nozzle. A variable convergent-divergent ramjet exhaust nozzle provides efficient ramjet operation over the desired operation range.

Pressures and temperatures establish environmental conditions, speed (N) influences bearing design and heat generation, and fuel flow establishes heat rejection capacity for design and analyses of the fuel and lubrication system. Pressures and temperatures exceed Mach 4 ram conditions. Engine speed (rpm) and fuel flow are shown in figure 84.



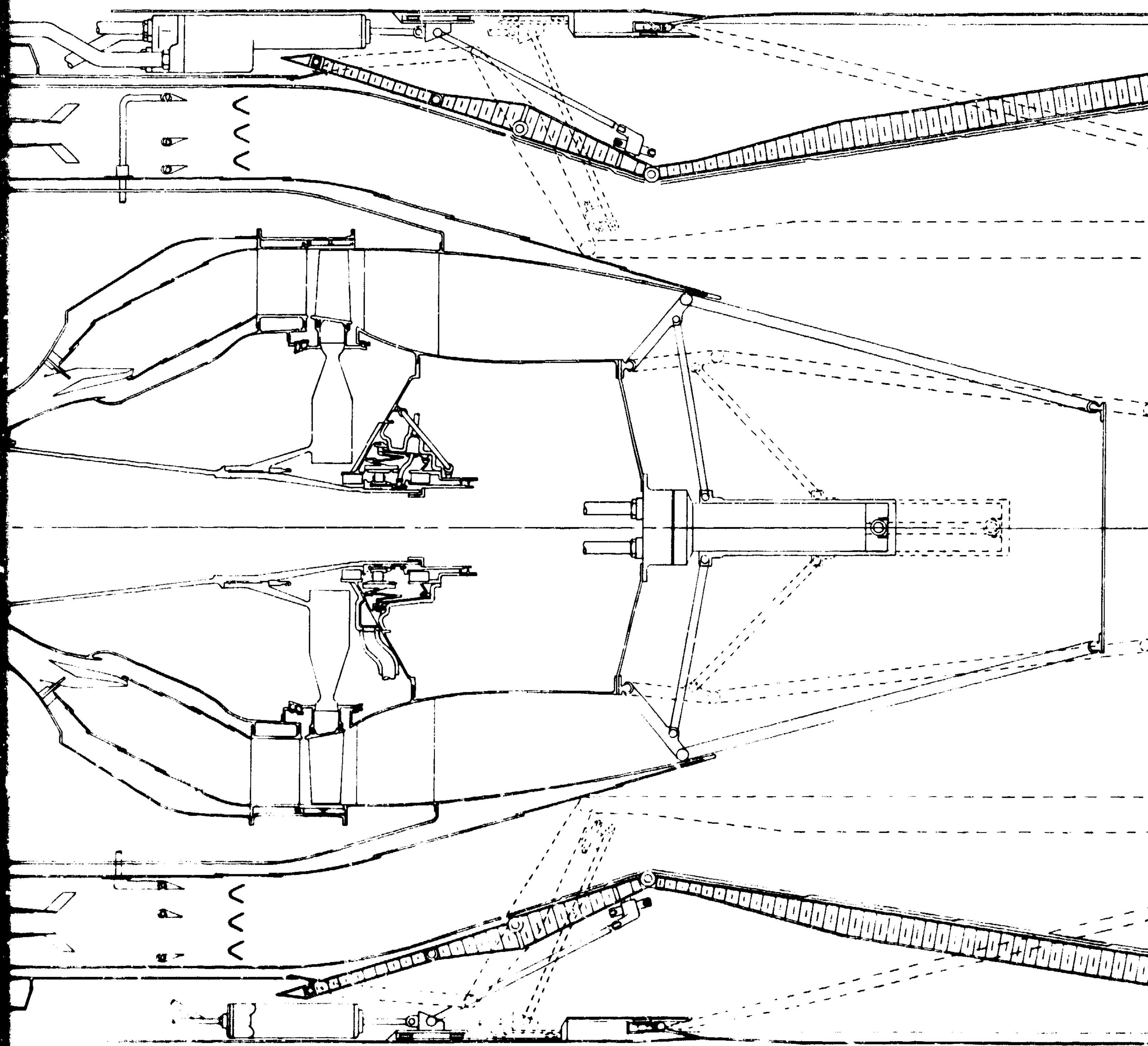
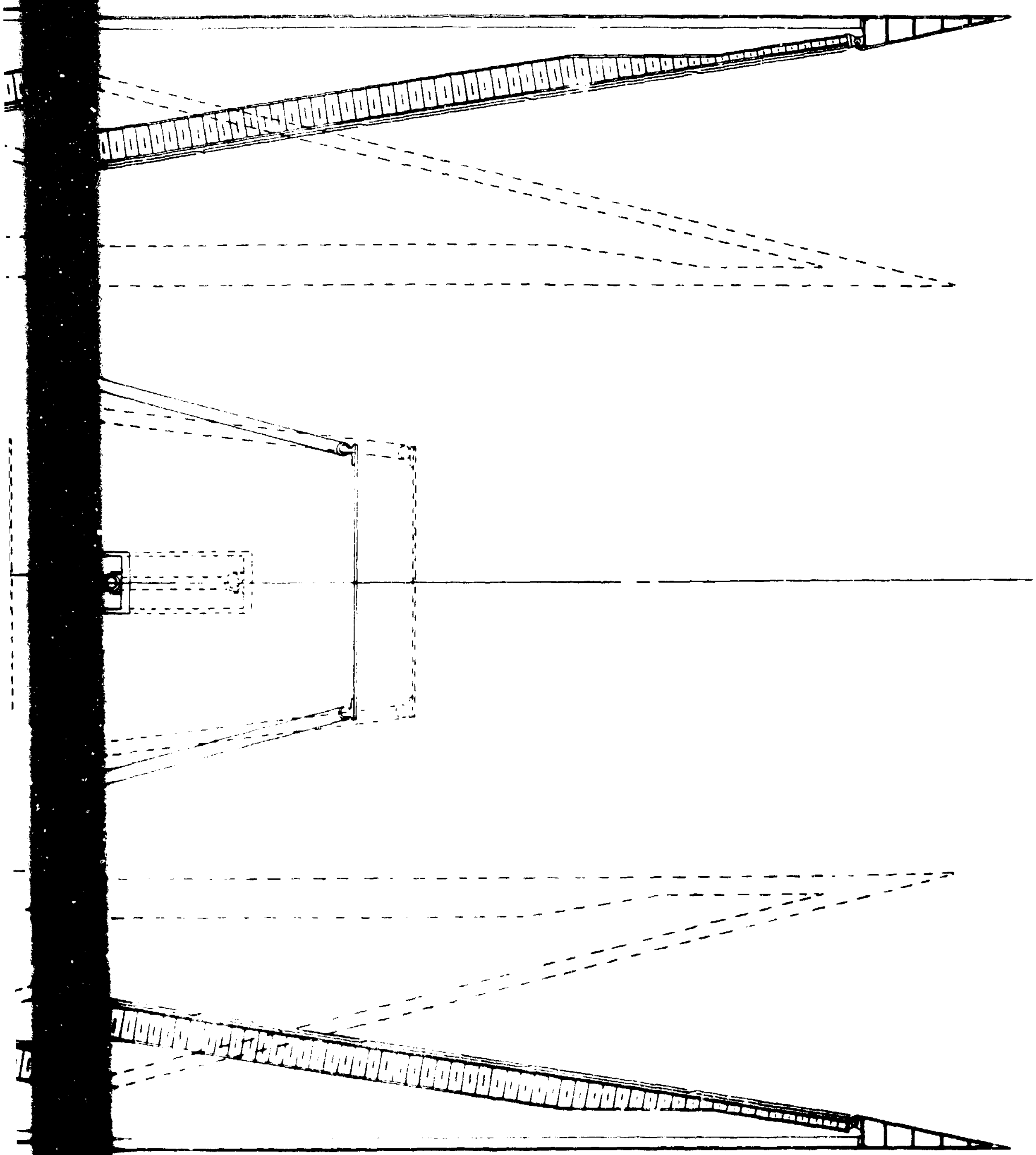


Figure 82. Selected STRJ334B Engine



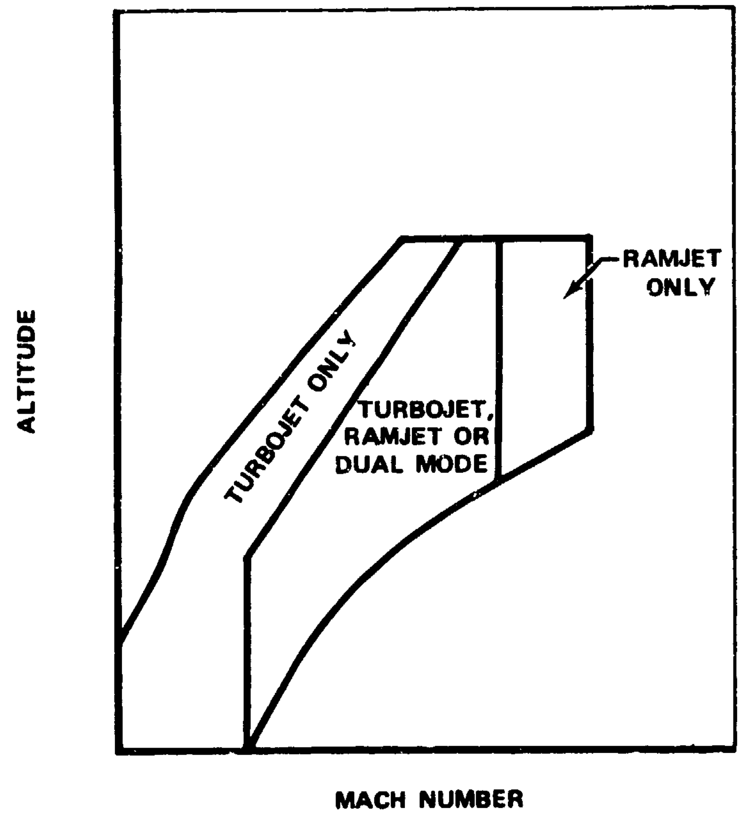


Figure 83. STRJ334B Operating Envelope

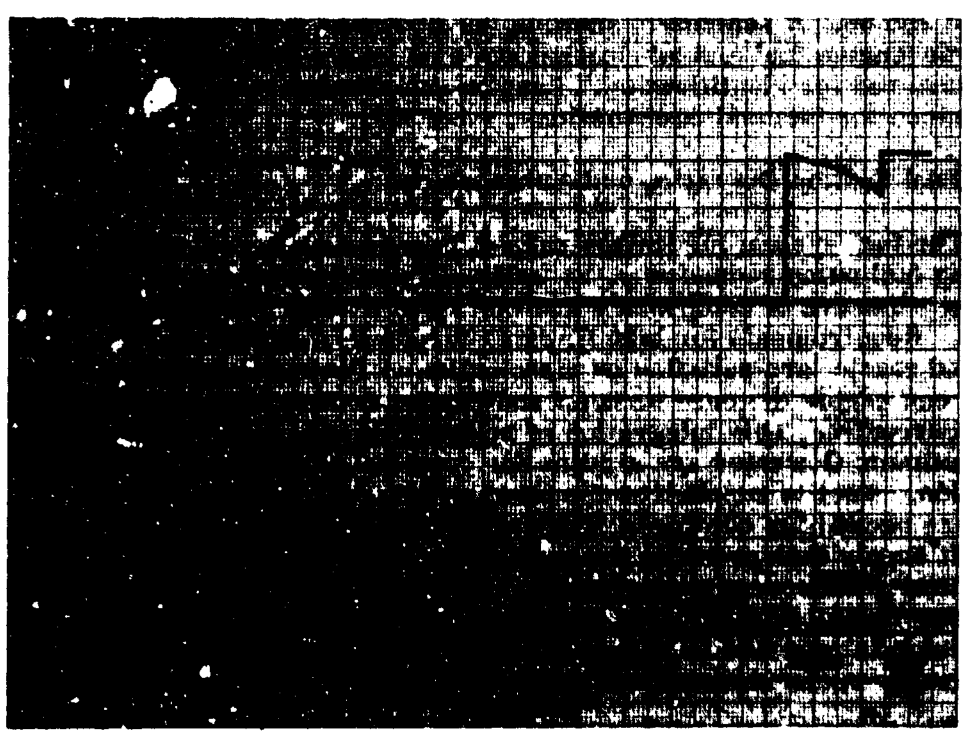


Figure 84. STRJ334B Operating Parameters During the High Mn Mission

C. STRJ334B FUEL AND LUBRICATION SYSTEM DESCRIPTION

The fuel and lubrication system, used as a baseline for the study of fuels and lubricants influence on the design and performance of the STRJ334B engine, was selected from several alternatives to provide the following key features:

- An air-bleed turbine drives accessories using compressor discharge bleed air to power the system when the turbojet core is operating and inlet bleed air during ramjet-only operation eliminating the conventional tower shaft and gearbox.

- Variable flow fuel pumps minimize heat input by supplying only the pressure and flowrate demanded by the engine.

- A hydraulic motor drives oil pressure and scavenge pumps to maintain required turbojet lubricant flow during the ramjet mode of operation.

- All fuel and lubrication systems maintain continuous flow to prevent stagnation and overtemperature during all operating modes (turbojet core only, ramjet only, and dual mode).

- The control system computer is isolated from high fuel temperatures so that only metering components, which can be designed to be tolerant to fuel deposits, are in high fuel temperature locations.

The STRJ334B fuel and lubrication system components are shown in figures 85 and 86. A schematic showing the flowpaths and integration of the airframe/engine fuel and lubrication systems is provided in figure 87. Lines are numbered for identification. Lengths and diameters of these lines were determined for thermal computations, table XV.

1. Fuel System Operation and Arrangement

The fuel system minimizes parasitic increases in fuel temperature by avoiding fuel pump redundancy, by using efficient pumping systems, and by limiting exposure of components and fuel lines to high environmental temperatures. Requirements for high flowrate turndown ratios for both the turbojet core and ramjet are satisfied by distribution of flow after pumping so that two pumps can supply the core turbojet and ramjet combustors, either individually or concurrently. This integration of requirements is possible since minimum and maximum flowrates are similar for core-only, ramjet-only, and dual mode operation. Fuel is supplied to the pump system after passing through heat exchangers needed for cooling aircraft systems. A fuel boost pump located at the aircraft supply tank provides the inlet pressure requirements of engine pumps. To minimize unnecessary parasitic heating, the initial thermal analysis assumed no engine-mounted boost pump upstream of main engine pumps. The aircraft boost pump is assumed to be controlled to pump only the flow demand of the engine plus that for recirculation for supplementary cooling.

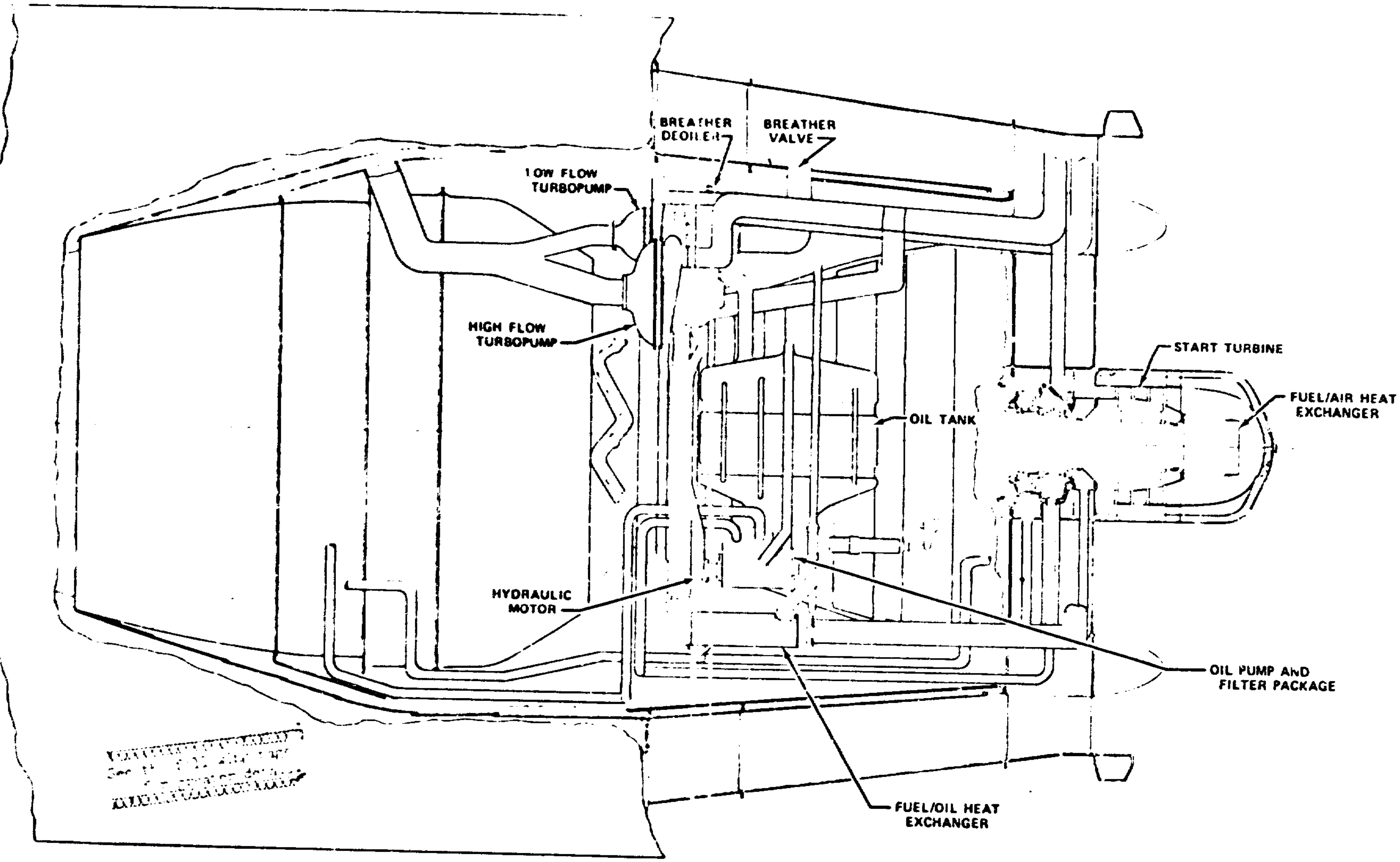


Figure 85. STRJ334B Fuel and Lubrication System, Right-Hand Side

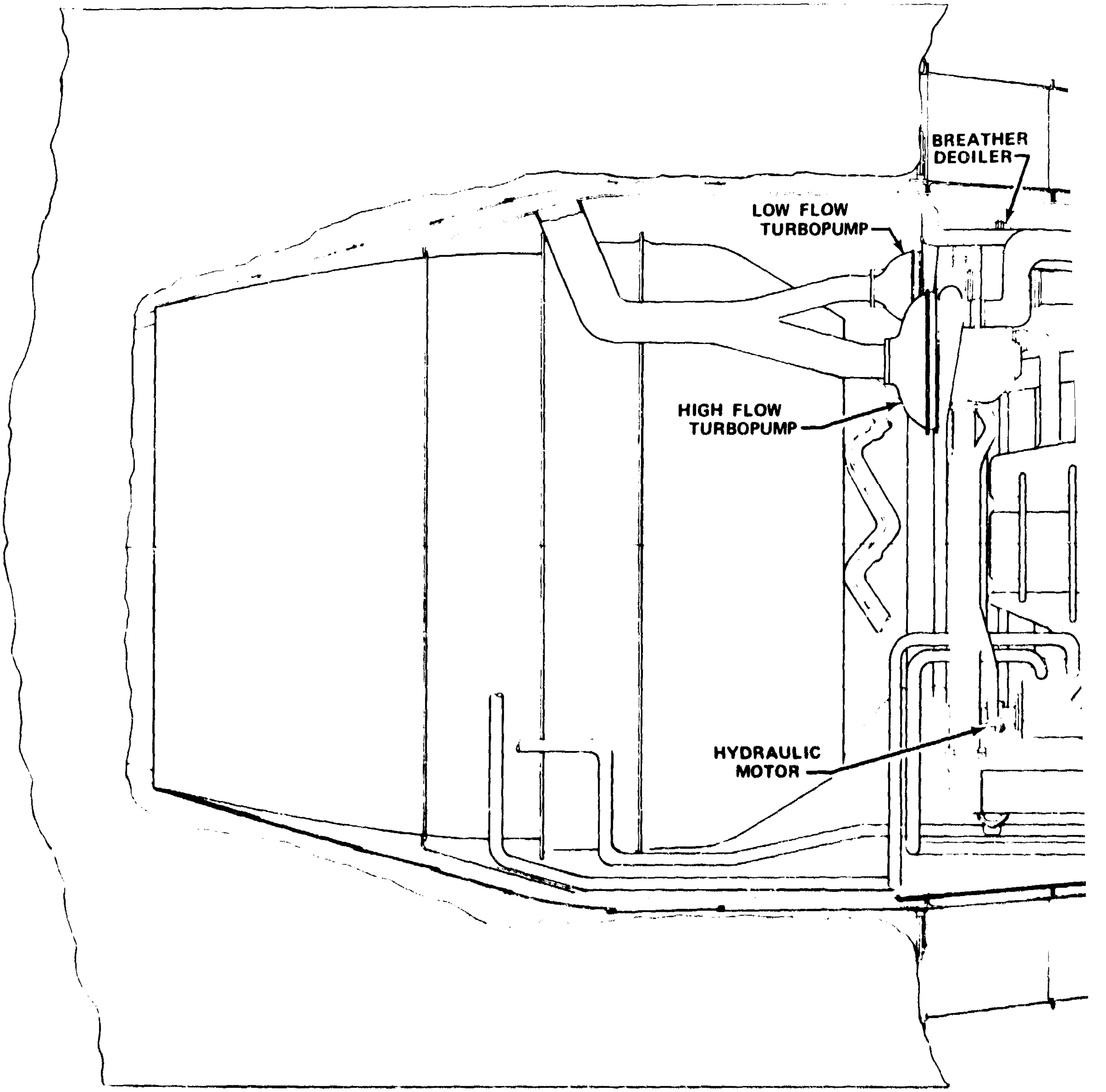
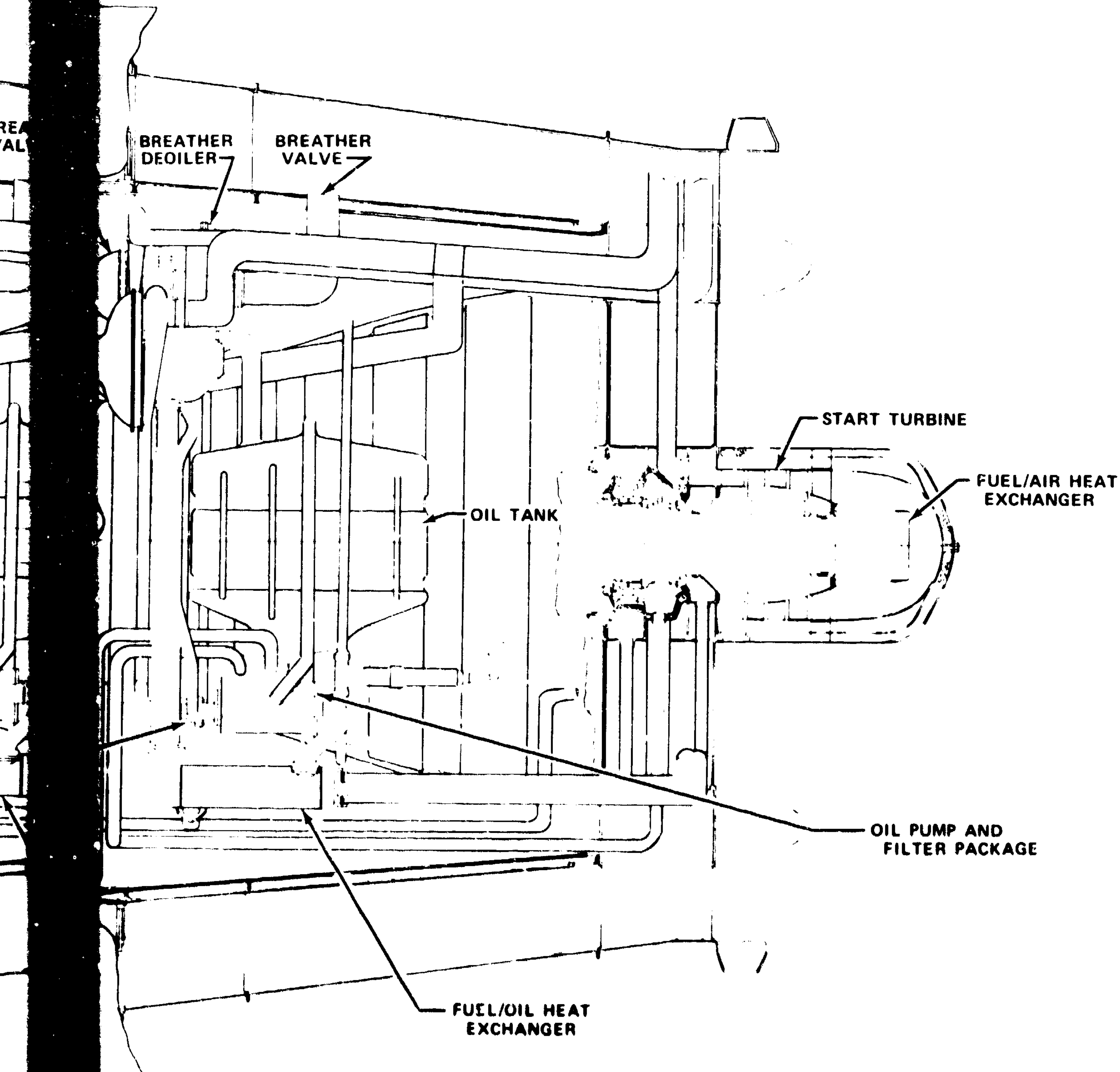
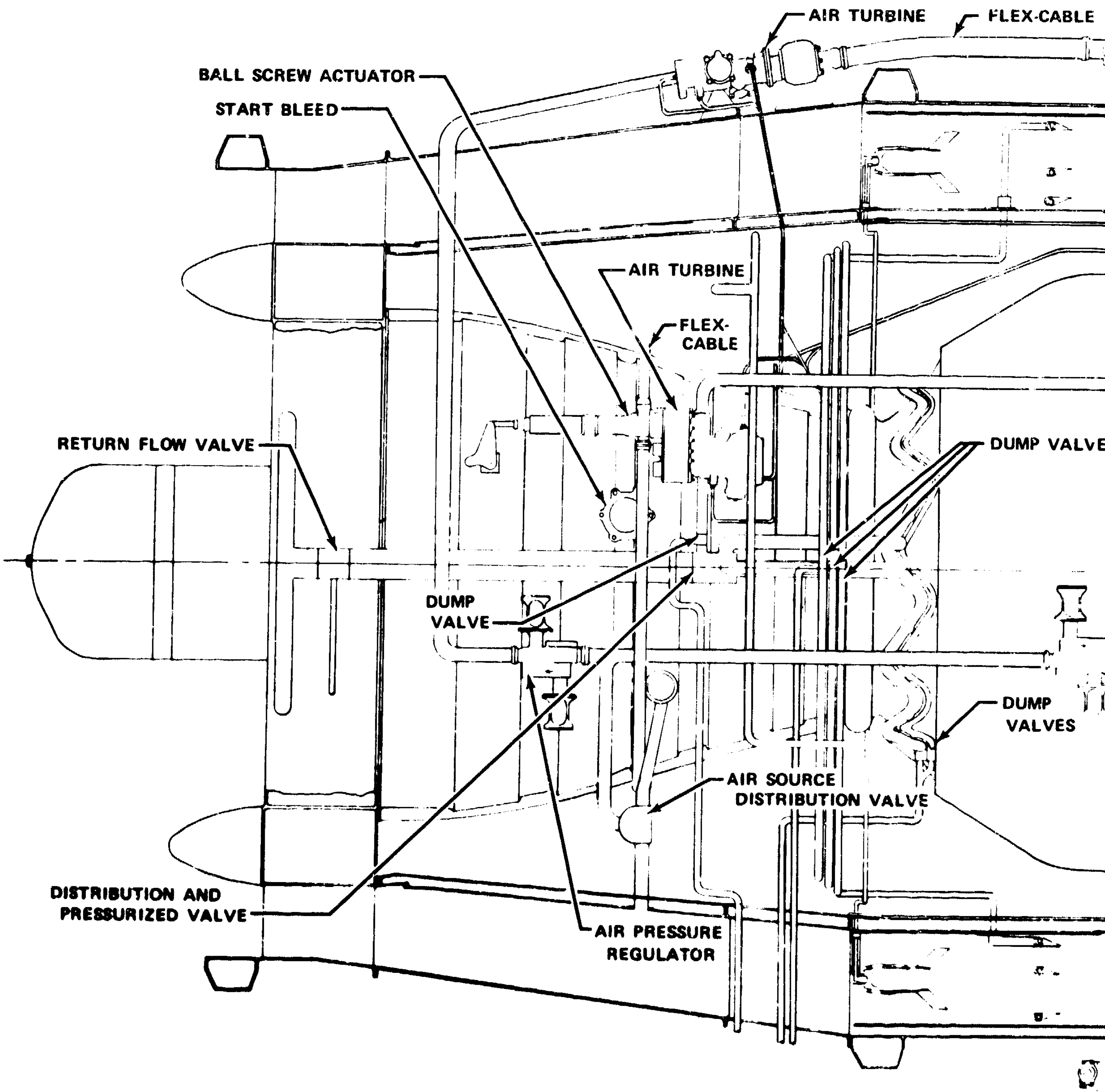


Figure 85. STRJ334B Fuel and Lubrication Sy

A



te and Lubrication System, Right-Hand Side


AIR TURBINE
FLEX-CABLE
BALL SCREW ACTUATOR
START BLEED
AIR TURBINE
FLEX-
CABLE
RETURN FLOW VALVE
DUMP VALVE
DUMP
VALVE
DUMP
VALVES
AIR SOURCE
DISTRIBUTION VALVE
DISTRIBUTION AND
PRESSURIZED VALVE
AIR PRESSURE
REGULATOR

Figure

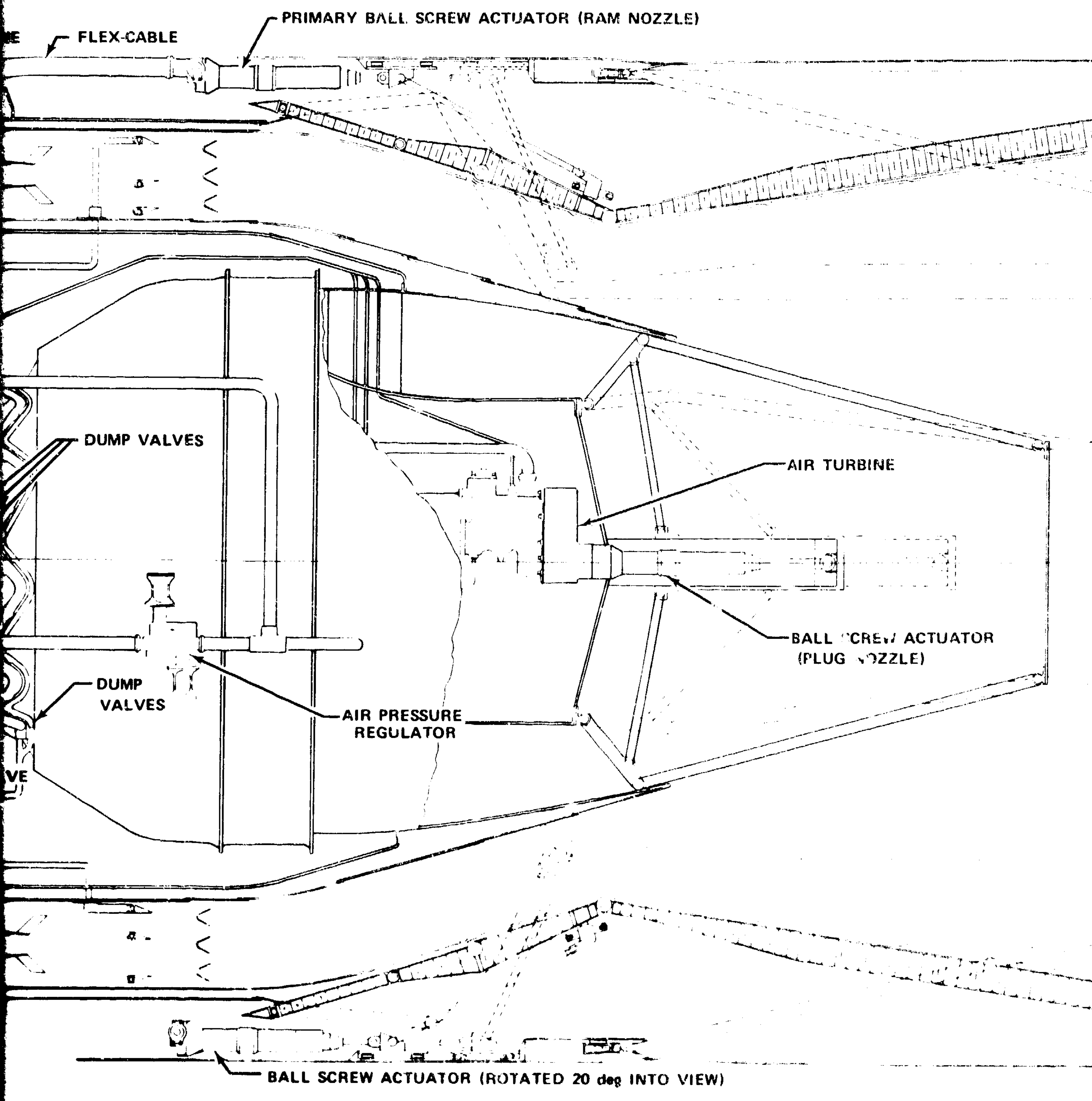
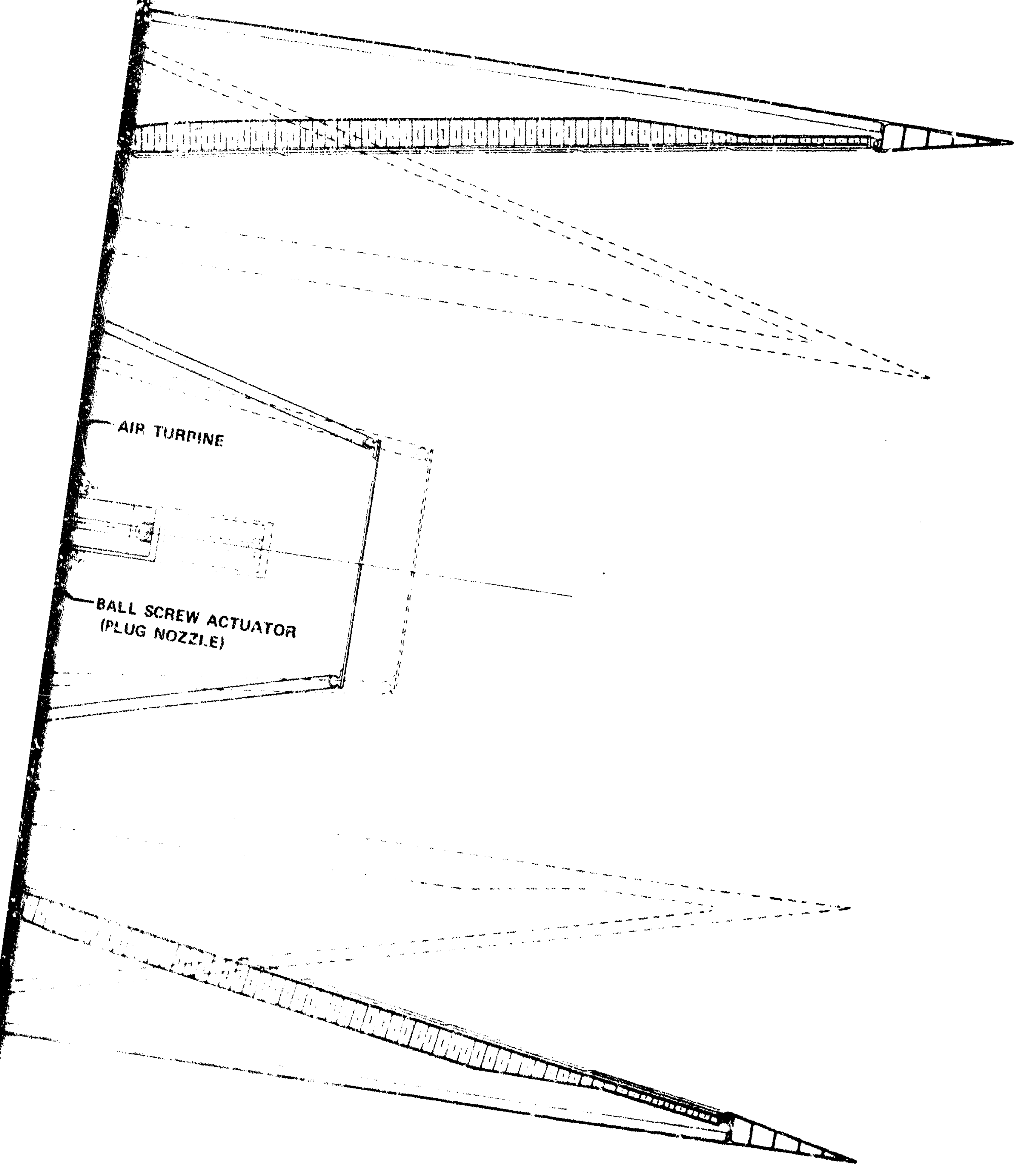


Figure 86. STRJ334B Fuel and Lubrication System, Left-Hand Side


AIR TURBINE
BALL SCREW ACTUATOR
(PLUG NOZZLE)

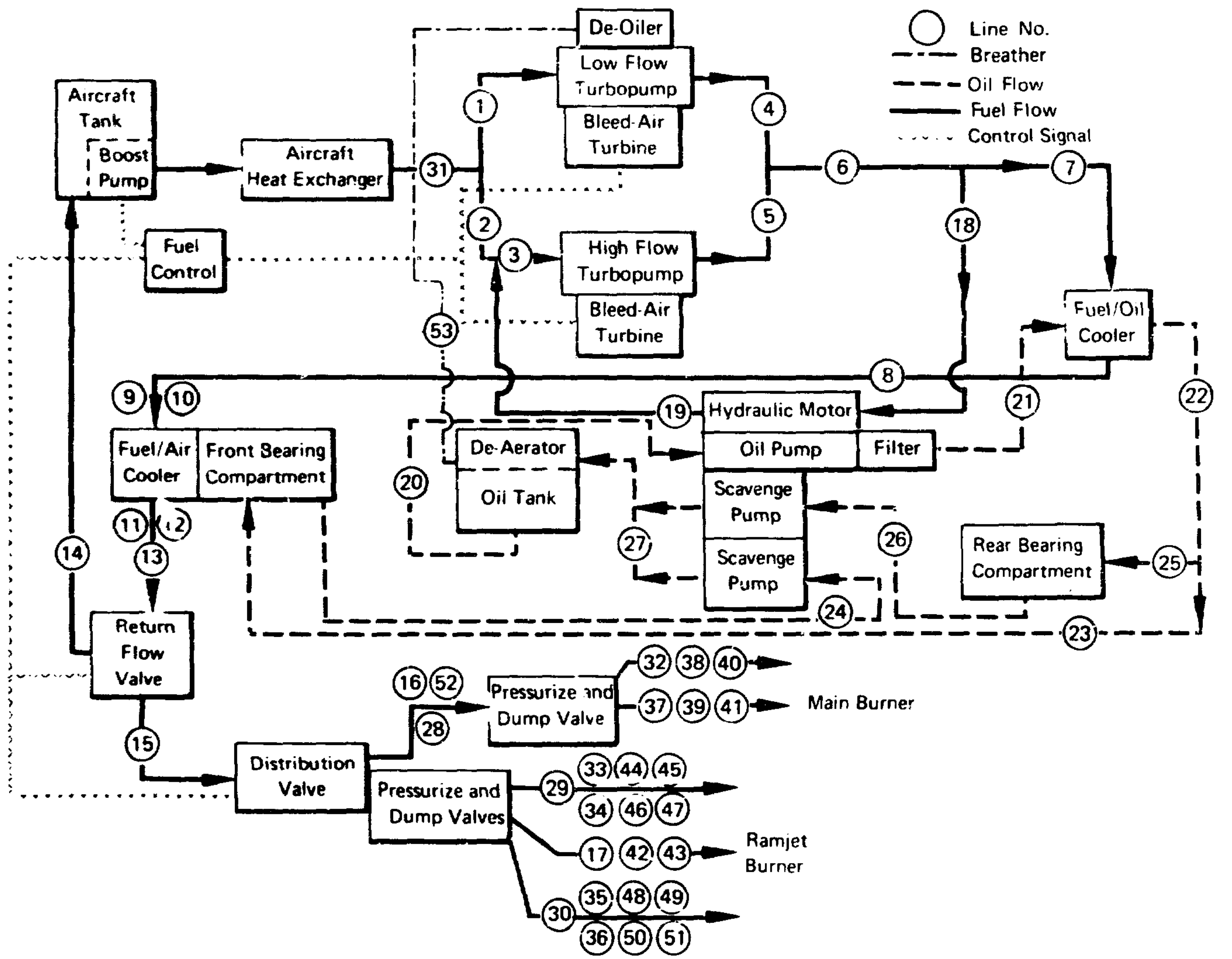


Figure 87. STRJ334B Fuel and Lubrication Baseline Schematic

Table XV. STRJ334B Fuel and Lubrication System Lines

Tube No.	Fluid	Line Name	Length, in.	Diameter, in.
1	Fuel	Low Pump Supply	8.00	1.00
2	Fuel	High Pump Supply	4.00	1.70
3	Fuel	High Pump Supply	4.00	1.70
4	Fuel	Low Pump Discharge	10.00	1.00
5	Fuel	High Pump Discharge	3.00	1.70
6	Fuel	Combined Pump Discharge	10.00	2.40
7	Fuel	Oil Cooler In	16.00	2.25
8	Fuel	Oil Cooler Out	28.00	2.25
9	Fuel	Air Cooler In	30.00	1.35
10	Fuel	Air Cooler In	40.00	1.35
11	Fuel	Air Cooler Out	36.00	1.35
12	Fuel	Air Cooler Out	36.00	1.35
13	Fuel	Combined Air Cooler Out	1.70	2.25
14	Fuel	Airframe Return	24.00	0.40
15	Fuel	Distribution Valve Supply	25.00	2.25
16	Fuel	Main Burner Supply	14.40	1.20
17	Fuel	Ramjet Manifold Supply	21.60	0.80
18	Fuel	Hydraulic Motor Supply	12.00	0.50
19	Fuel	Hydraulic Motor Return	28.00	0.50
20	Oil	Oil Pump Supply	2.00	1.70
21	Oil	Oil Cooler In	12.00	1.25
22	Oil	Oil Cooler Out	4.00	1.25
23	Oil	Front Bearing Supply	55.20	0.90
24	Oil/Air	Front Bearing Scavenge	80.00	0.90
25	Oil	Rear Bearing Supply	65.80	0.90
26	Oil/Air	Rear Bearing Scavenge	86.50	0.90
27	Oil/Air	Oil Tank Return	24.00	1.00
28	Fuel	Main Burner Supply	36.80	1.10
29	Fuel	Ramjet Manifold Supply	14.00	1.10
30	Fuel	Ramjet Manifold Supply	15.20	1.10
31	Fuel	Engine Inlet	44.00	3.00
32	Fuel	Main Burner Manifold In	4.80	0.80
33	Fuel	Ramjet Manifold	8.80	0.80
34	Fuel	Ramjet Manifold	9.20	0.80
35	Fuel	Ramjet Manifold	3.00	0.80
36	Fuel	Ramjet Manifold	3.00	0.80
37	Fuel	Main Burner Manifold In	13.60	0.80
38	Fuel	Main Burner Manifold	76.40	0.55
39	Fuel	Main Burner Manifold	74.80	0.55
40	Fuel	Main Burner Manifold	82.90	0.30
41	Fuel	Main Burner Manifold	120.60	0.30
42	Fuel	Ramjet Sprayring Supply	109.20	0.30
43	Fuel	Ramjet Sprayring	227.40	0.55
44	Fuel	Ramjet Sprayring Supply	127.80	0.55
45	Fuel	Ramjet Sprayring	206.70	0.30
46	Fuel	Ramjet Sprayring Supply	120.90	0.30
47	Fuel	Ramjet Sprayring	156.00	0.30
48	Fuel	Ramjet Sprayring Supply	129.80	0.55

Table XV. STRJ334B Fuel and Lubrication System Lines (Continued)

Tube No.	Fluid	Line Name	Length, in.	Diameter, in.
49	Fuel	Ramjet Sprayring	214.80	0.30
50	Fuel	Ramjet Sprayring Supply	118.20	0.55
51	Fuel	Ramjet Sprayring	179.70	0.30
52	Fuel	Main Burner Manifold	104.00	0.85
53	Air/Oil	Breather	13.60	1.00

The STRJ334B turboramjet fuel system lines are identified in figure 87. These line numbers are used to facilitate the following description of the fuel system operation:

- Fuel into the engine enters the cavity between the turbojet core and the ramjet through a ramjet inlet strut (line 31) and divides to supply the high and low range turbopumps (lines 1 and 2). Fuel is supplied by the aircraft boost pumps to satisfy engine flow, any cooling recirculation flow, and minimum net positive suction pressure (NPSP) requirements.

- The total flow output of the low range (30,000 lb/hr maximum) turbopump and the high range (100,000 lb/hr maximum) turbopump (lines 4 and 5 combining to 6) would be controlled to match the total turbojet core, ramjet, and oil pump hydraulic motor demands, minimizing parasitic pumping heat generation. This can be accomplished by controlling the speed of the bleed-air-turbines driving the positive displacement pumps. Additional flow for extraordinary cooling requirements would also be supplied and returned to aircraft tanks.

- The fuel-operated hydraulic motor operates on the fuel pressure differential across the turbopumps (between supply line 18 and discharge line 19) to drive the oil pressure and scavenge pumps for turbojet lubrication during all modes of operation, including ramjet only.

- The total engine flow (line 7) passes through the fuel/oil cooler to provide lubricant cooling in all operating modes.

- The discharge from the fuel/oil cooler (line 8) is divided (lines 9 and 10) to reduce line sizes for passage through the turbojet inlet struts to the fuel/air cooler. This cooler provides cooling air for the turbojet core during ramjet-only operation. During concurrent operation of the core engine and ramjet, flow through this cooler is maintained to prevent stagnation of fuel at maximum turbojet stagnation temperatures. Unnecessary heating of fuel in this heat exchanger when the core engine is operating may be minimized by shutting off heat exchanger airflow. Fuel from the air cooler passes through inlet struts (lines 11 and 12) and recombines (line 13).

- A return loop to the aircraft tank (line 14) provides the option for returning fuel to the aircraft tank if engine cooling demands exceed the available heat sink of the engine fuel flow.

- The total engine fuel flow (line 15) is proportioned to satisfy individual ramjet and turbojet demand by controlling the distribution valve. A component design goal would be to design the distribution valve and fuel injectors for maximum tolerance to potential products of fuel thermal decomposition since these areas experience higher fuel temperature conditions than any other part of the system. Distribution of fuel for the turbojet main burner and ramjet burner is provided by the network of supply and manifold lines shown in figures 86 and 87.

Fuel system component performance characteristics are contained in Appendix III; following are general descriptions of primary components.

2. STRJ334B Fuel System Components

The STRJ334B high and low range fuel pumps, shown in figures 88 and 89, are sized to deliver a maximum combined flow of 130,000 lb/hr. They are turbine-driven, positive displacement vane pumps that provide variable fuel flow on demand by controlling turbine speed. The turbine is powered with compressor discharge air when the turbojet core is operating and inlet bleed air during the ramjet mode. The pump flow is controlled by regulating this air supply to vary turbine speed. The two positive displacement vane pumps would normally operate in parallel. Fuel flow capacities are 100,000 lb/hr at 7500 rpm for the high range pump and 30,000 lb/hr at 14,000 rpm for the low range pump. High speed designs for these pumps enhance turbine efficiency and provide smaller pumps.

Speed, efficiency, and configuration trades for both the pump and turbine were analyzed, since this is a new system for which previous optimum design data are not available. Speed, diameter, vane length/diameter, and efficiency characteristics were parametrically plotted for the vane pumps at maximum flow and 500-psi pressure rise. To permit direct turbine drive, a compromise must be made between the low pump speed desired to increase fuel pumping efficiency and the high speed desired for maximum turbine efficiency. The compromise selected for the baseline design provides relatively high speeds at maximum flows, since improved turbine efficiency more than offsets relatively low (48%) fuel pump efficiency. The fuel pump efficiency should not be critical at this high flow condition, and at low flows, where fuel heat pickup could be critical, the pump efficiency would be above 65%.

The hydraulic motor, figure 90, provides independent drive of the oil system pressure and scavenge pumps for turbojet lubrication and cooling during all modes of operation. Fuel is used to drive the gear motor at speeds up to 4000 rpm. The differential fuel pressure for this drive is provided by the main fuel pumps.

The fuel/oil heat exchanger for the baseline system is shown in figure 91. The design is a shell-tube type with fuel flowing through the tubes and oil flowing through a labyrinth passage around the tubes.

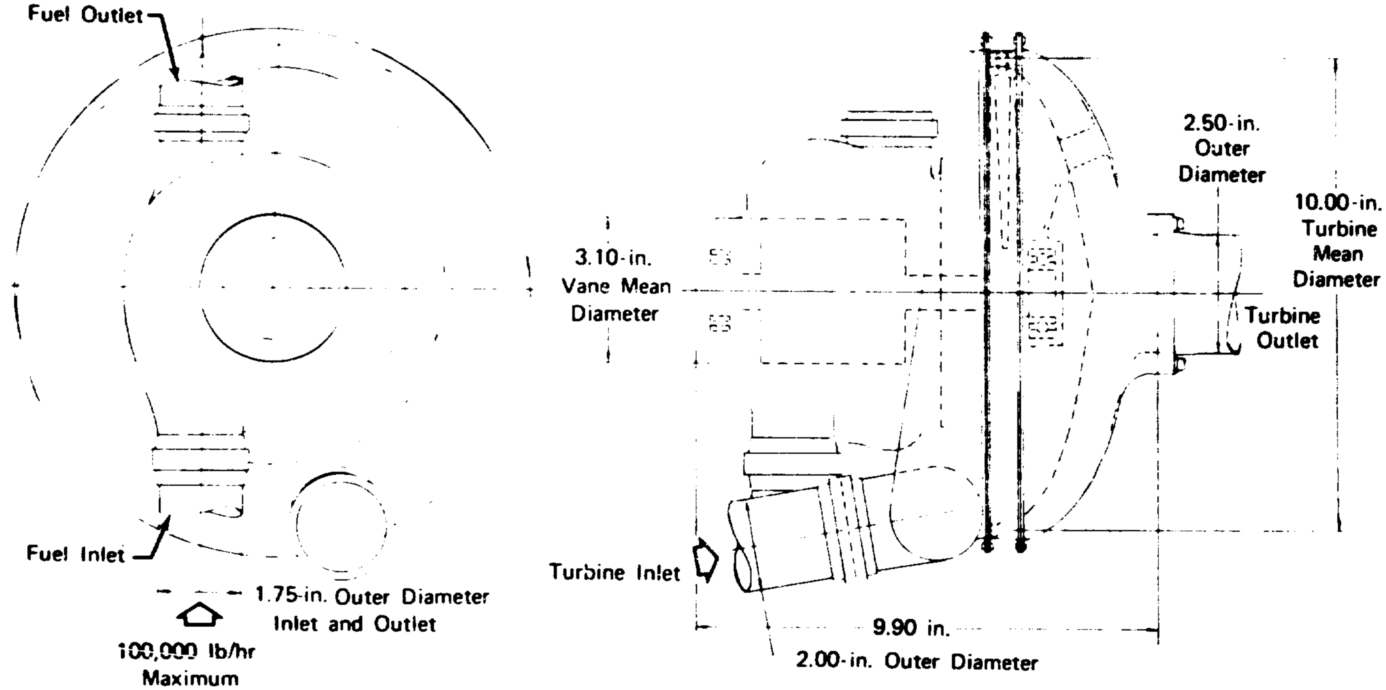


Figure 88. STRJ334B High Range Fuel Pump

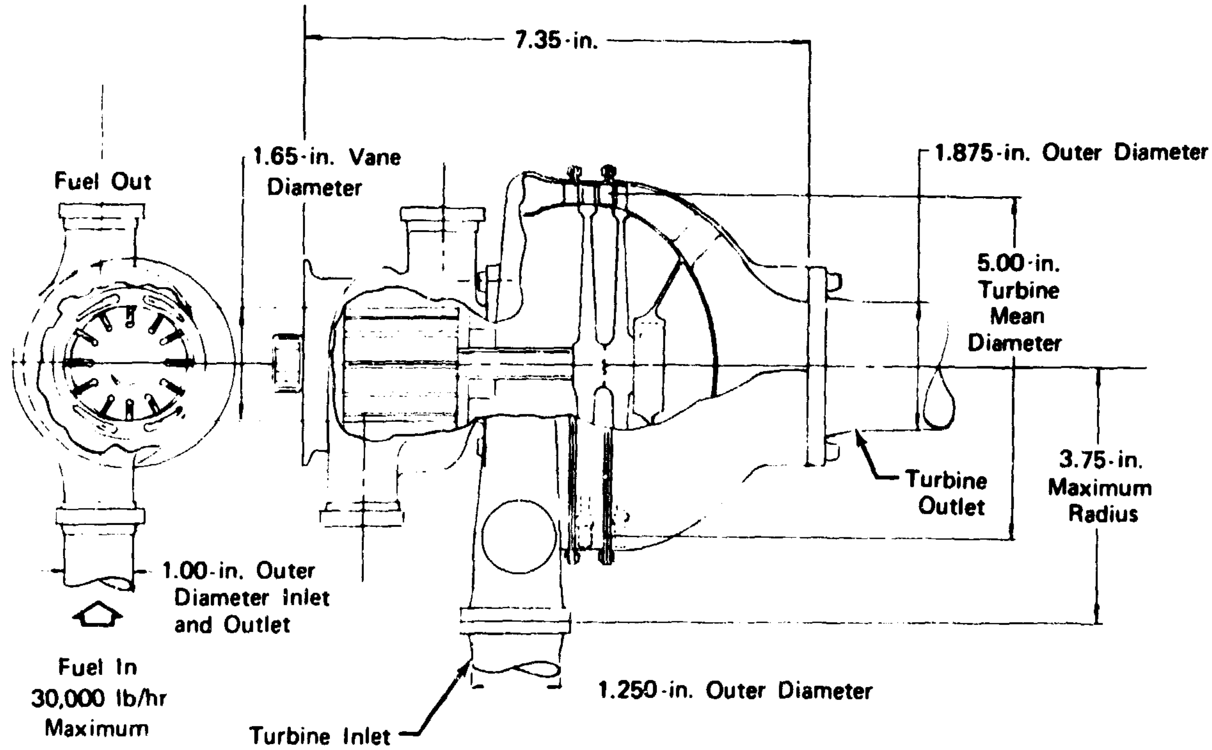


Figure 89. STRJ334B Low Range Fuel Pump

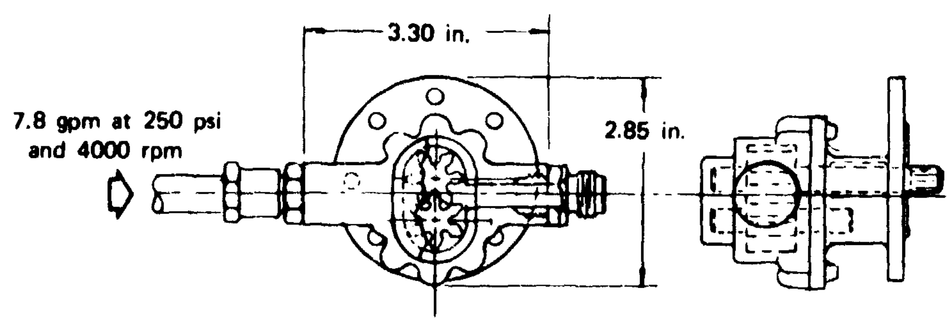


Figure 90. Fuel-Powered Hydraulic Motor

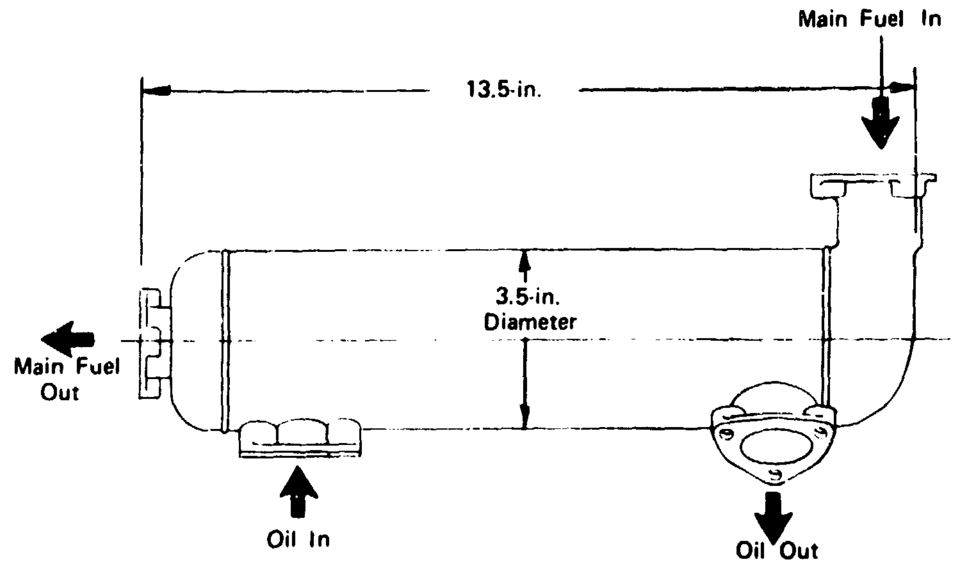


Figure 91. STRJ334B Fuel/Oil Heat Exchanger

3. STRJ334B Lubrication System Operation and Arrangement

The baseline lubrication system for the STRJ334B turboramjet provides lubrication and cooling for the two bearing compartments (figures 92 and 93) of the turbojet core. Gearboxes were avoided through the use of bleed air turbine drives for engine and aircraft accessories, minimizing lubrication system requirements. The following baseline lubrication system description refers to line numbers identified in figure 87:

- From the tank, the lubricant flows through line 20 to the pressure supply pump and filter, which are integrated with the scavenge pumps. The pumps in this assembly are driven by a fuel-powered hydraulic motor. Line 21 close-couples the pump and filter assembly to the cooler. After the fuel/oil cooler, the lubricant is distributed (line 22) to the front bearing (line 23) and rear bearing (line 25) compartments.

- Scavenge oil and breather air return from each of the bearing compartments (lines 24 and 26) to individual scavenge pumps incorporated in the integrated oil pump and filter assembly. By driving the oil pressure and scavenge pumps with a fuel-operated hydraulic motor, it is possible to maintain a high turbojet lubrication and cooling flow while the engine is in the ramjet operating mode.

- The scavenge pumps return the oil and breather air to the oil tank (line 27) through a deaerator. The released breather air is vented (line 53) from the tank through a centrifugal deoiler driven by the low range fuel pump air turbine. Oil separated from breather air returns to the tank by gravity through a concentric line.

- Components of the oil system are placed in the sheltered cavity between the turbojet core and the wraparound ramjet, providing a system that is readily adaptable to effective insulation.

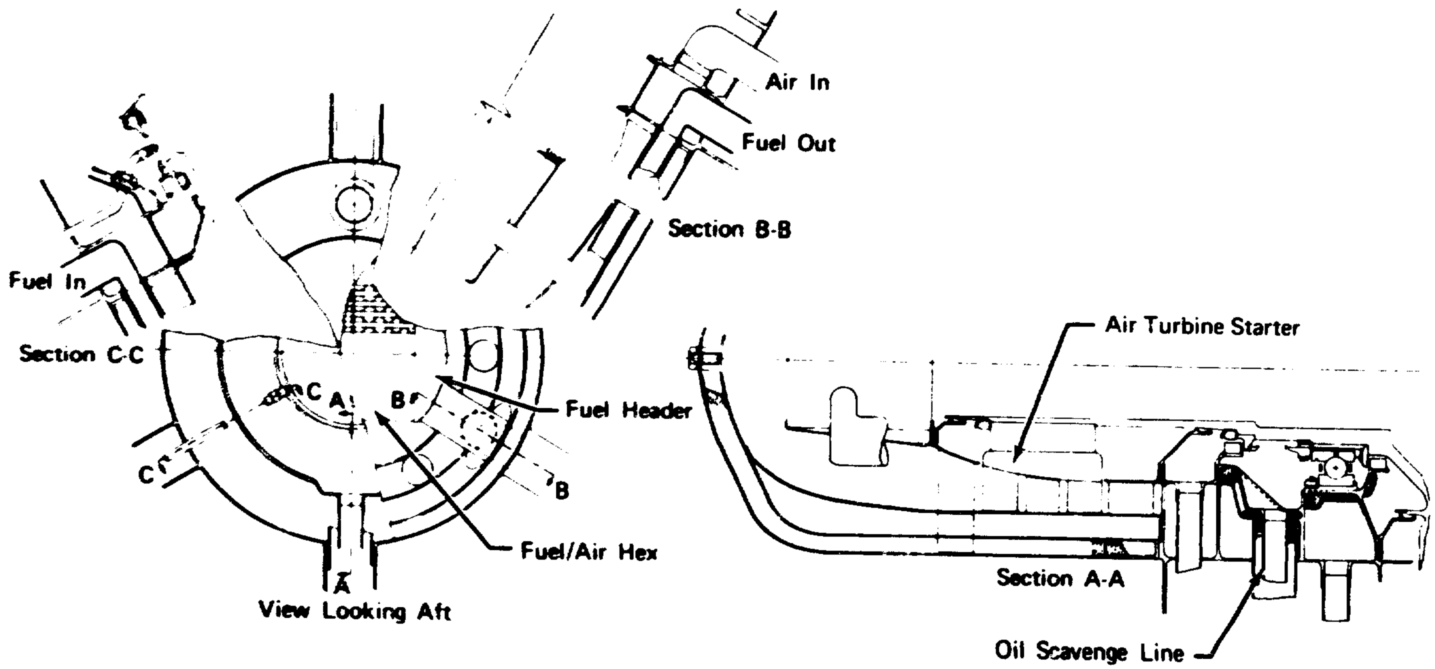


Figure 92. STRJ334B Front Bearing Compartment

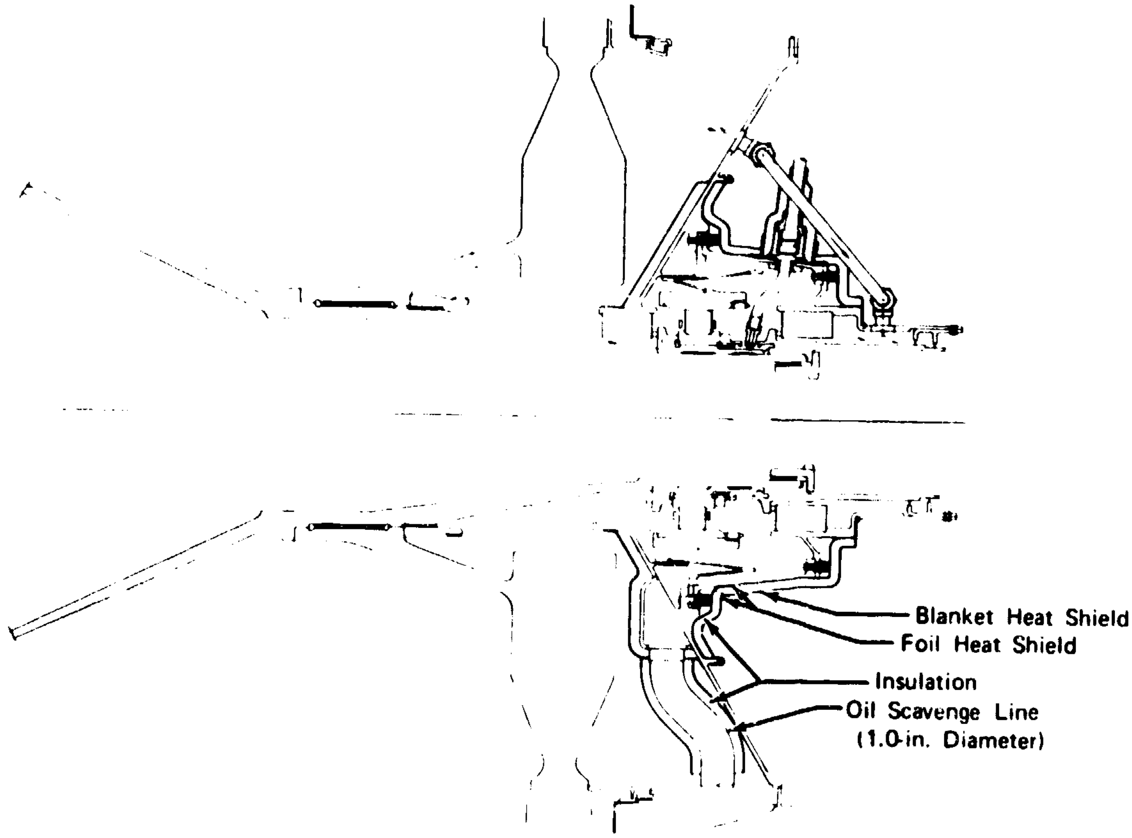


Figure 93. STRJ334B Rear Bearing Compartment

Lubrication system component performance characteristics are contained in Appendix III; primary features are discussed in the following paragraphs.

4. STRJ334B Lubrication System Components

The STRJ334B oil tank, shown in figure 94, is located on the right side between the turbojet core and the ramjet. The tank capacity is 2 gal. This small size is an ancillary benefit of the low oil consumption required for the two-bearing, gearboxless engine configuration. The oil inlet line in the tank includes an antisiphon feature and discharges in a deaerator. The tank breather vent discharges into the centrifugal deoiler.

The pumps and filter, illustrated in figure 95, are integrated into a compact assembly of the pressure supply pump, filter, and two scavenge pumps. Scavenge pumps are sized to pump air and fuel from bearing compartments. The assembly is driven by a hydraulic motor described in the fuel system components section.

The front bearing compartment, shown in figure 92, consists of a single ball bearing with a stationary support. Insulation is provided on all stationary oil-wetted surfaces to reduce the heat transfer from the environment. Bleed air is used to pressurize the seals. Passages are provided to allow the jet supplied oil to lubricate and cool the bearing and cool the seal faces. The scavenge is provided at the bottom of the compartment. The compartment size is held to a minimum to reduce the area of oil-wetted surfaces exposed to high environmental temperatures.

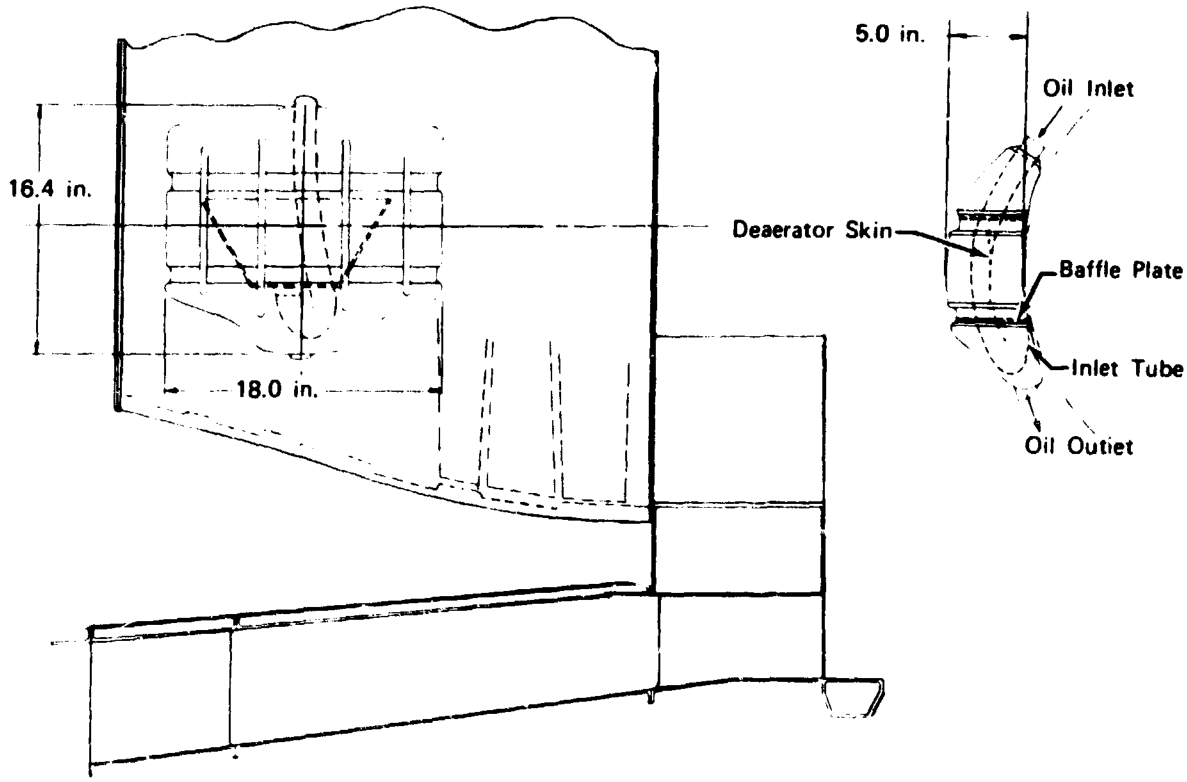


Figure 94. STRJ334B Oil Tank

The turbojet starting turbine is also shown in figure 92, since it is integral with the front bearing compartment. This turbine is used to slowly motor the core engine during the ramjet mode of operation. Core rotation at a minimum speed of 100 rpm is required to maintain a centrifugal force for oil circulation under bearing races and through seal plates. Flow through the turbine is forward. For ground starting, using a ground air supply, the turbine air discharges out the nose cone circumference. During ramjet operation, the turbine is powered by aircraft inlet bleed air, so it must discharge to a different location to provide adequate pressure differential. In this operating mode, the starting turbine will discharge into the nose cone and through the rotor bore and out the tail cone. In the process, the starter discharge air will pass through a fuel/air cooler, as shown in figure 92, to cool the core of the turbojet during ramjet operation. The fuel/air heat exchanger is a flat tube type, with fuel headers on the inlet and outlet sides.

The rear bearing compartment for the baseline system is shown in figure 93. It incorporates a single roller bearing supported by an oil-damped spring structure. The design minimizes surface area on the hot side (front) of the compartment, reducing heat absorption. Both sides of the compartment are insulated to further reduce heat input. Turbine cooling air pressurizes the compartment seals. Passages are provided for oil to cool and lubricate the bearing, cool the seal faces, and provide dampening for the support. Oil is scavenged from the bottom of the compartment, and the drain line is sized for combined oil and breather airflow.

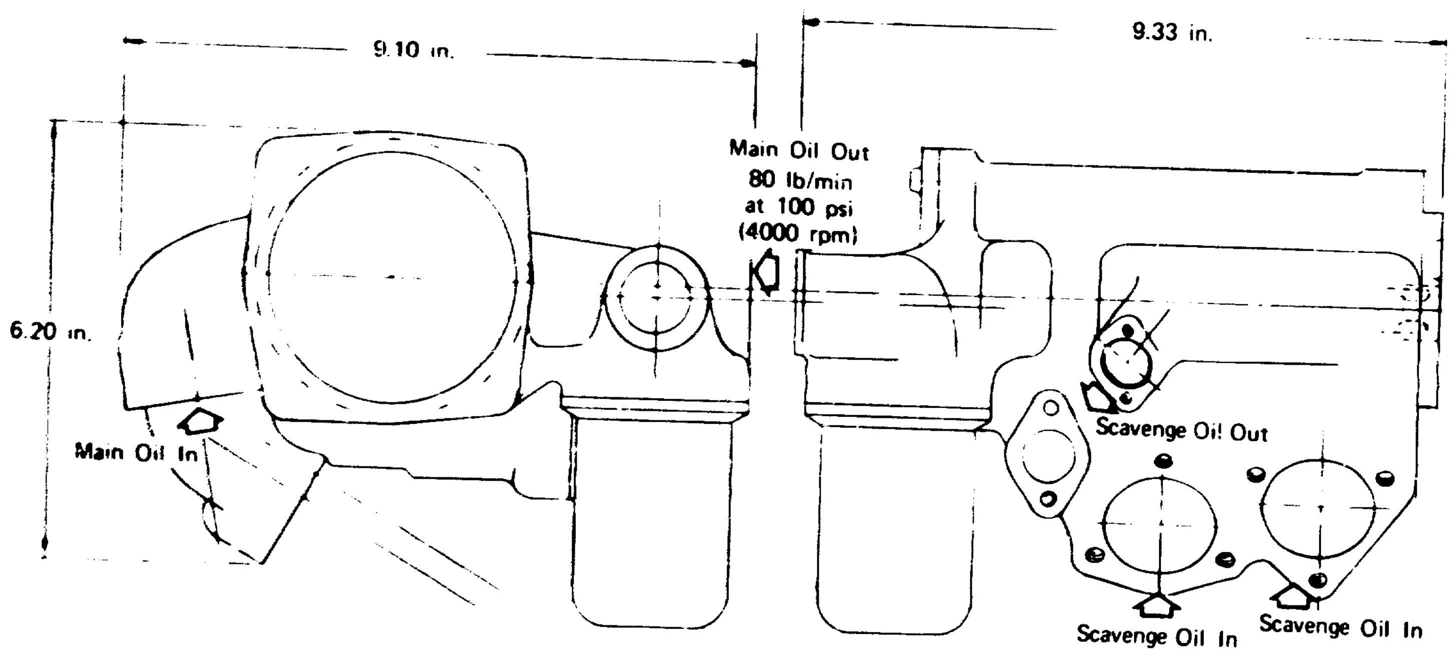


Figure 95. STRJ334B Oil Pumps and Filter

The breather deoiler, shown in figure 96, is needed because of the absence of a gearbox deoiler and breather vent. This unit is a centrifugal separator designed to be driven by a shaft extension from the low range fuel pump. Breather air vented from the oil tank will enter the outer circumference of the deoiler and exhaust on the center axis. Centrifugally separated oil will be returned by gravity to the oil tank.

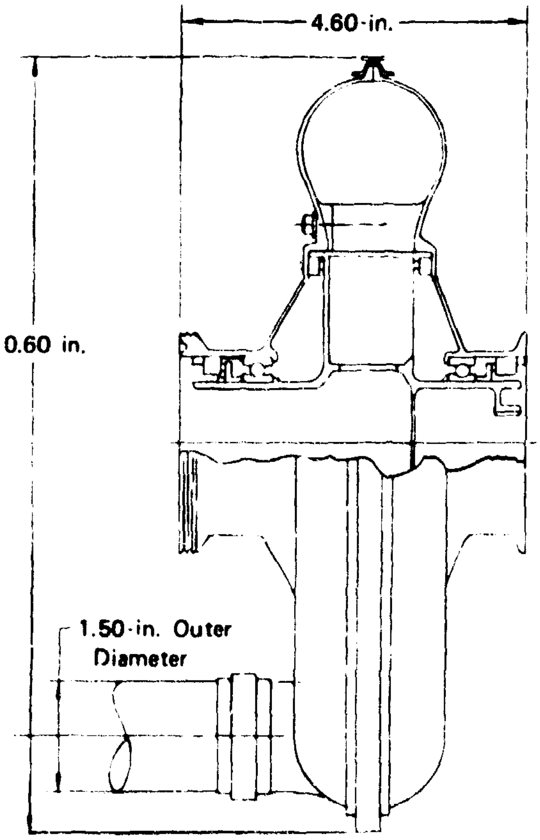


Figure 96. STRJ334B Centrifugal Breather Deoiler

D. STRJ334B FUEL AND LUBRICANT TEMPERATURES

Fuel and lubricant stream temperature profiles were computed for the STRJ334B engine. This was done using a computer model of the fuel and lubrication system described above, following the calculating procedure outlined by the flow chart in figure 97. Iterative calculations were used to balance the heat generation of the lubrication, fuel, and air systems with the heat absorption of the fuel system. (Appendix I contains a description of the computer program and sample printouts.) The program provided a rapid calculation of thermal conditions for the STRJ334B turboramjet fuel and lubrication system at selected points during the mission. Thirty flight conditions were analyzed to cover the range of speeds and altitude for the baseline mission. The Mach number and altitude distribution of these flight points are shown on figures 98 and 99. For each of the 30 mission points, the thermal conditions were computed for the STRJ334B baseline fuel and lubrication system.

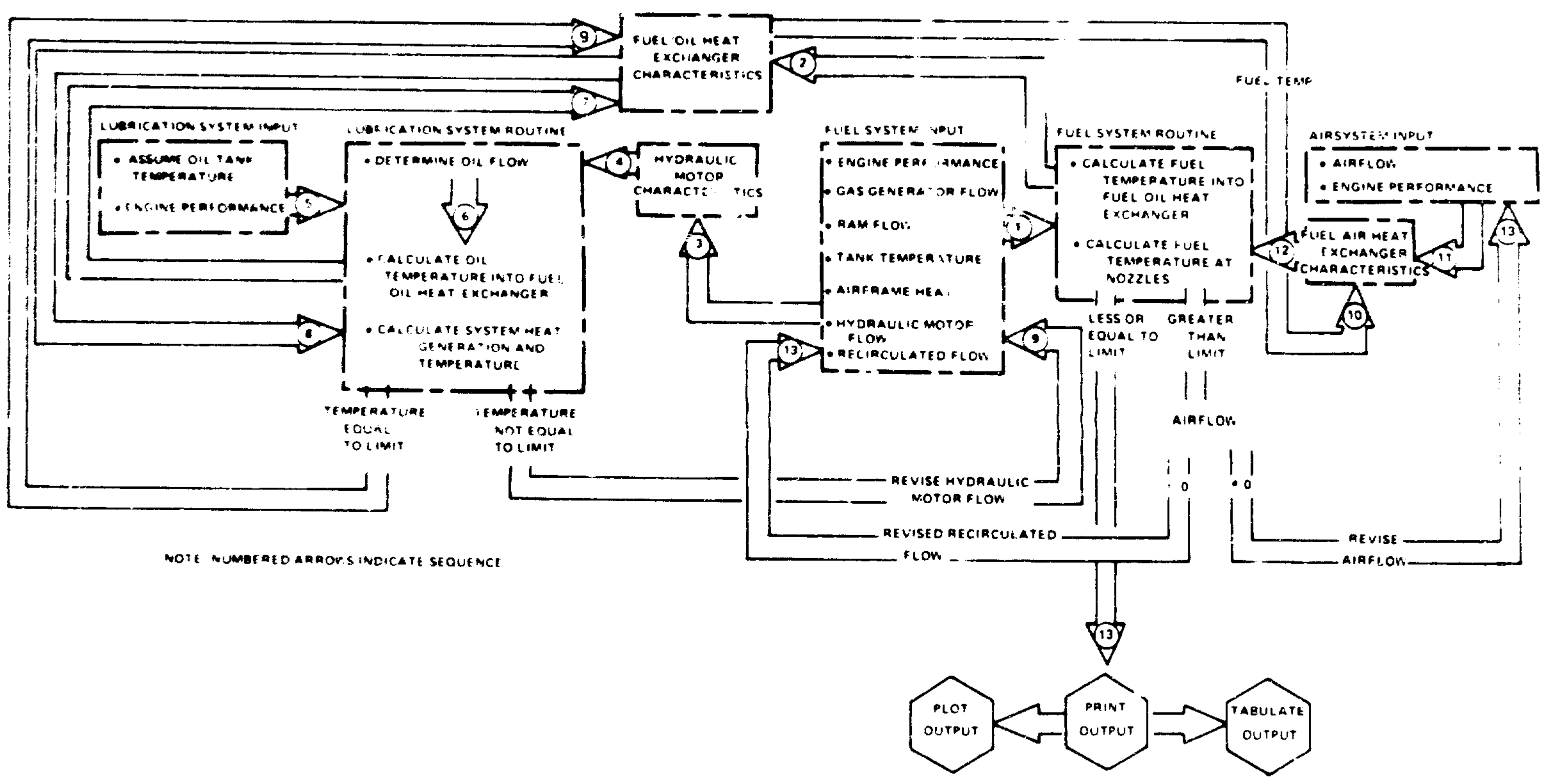


Figure 97. STRJ334B Engine Thermal Analysis Computer Program Flow Chart

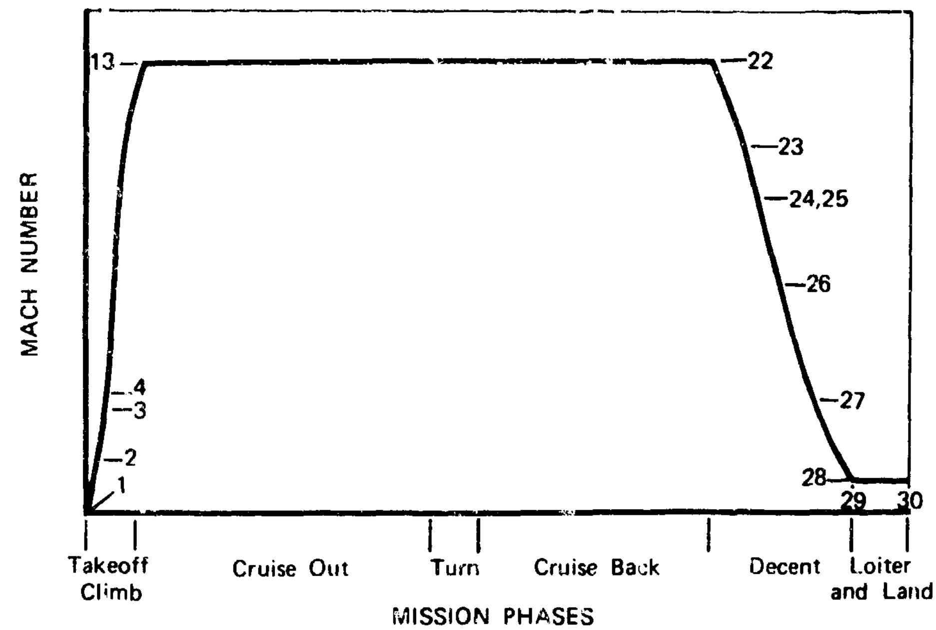


Figure 98. STRJ334B Thermal Analysis Computer Program Mission Mach Number Coverage

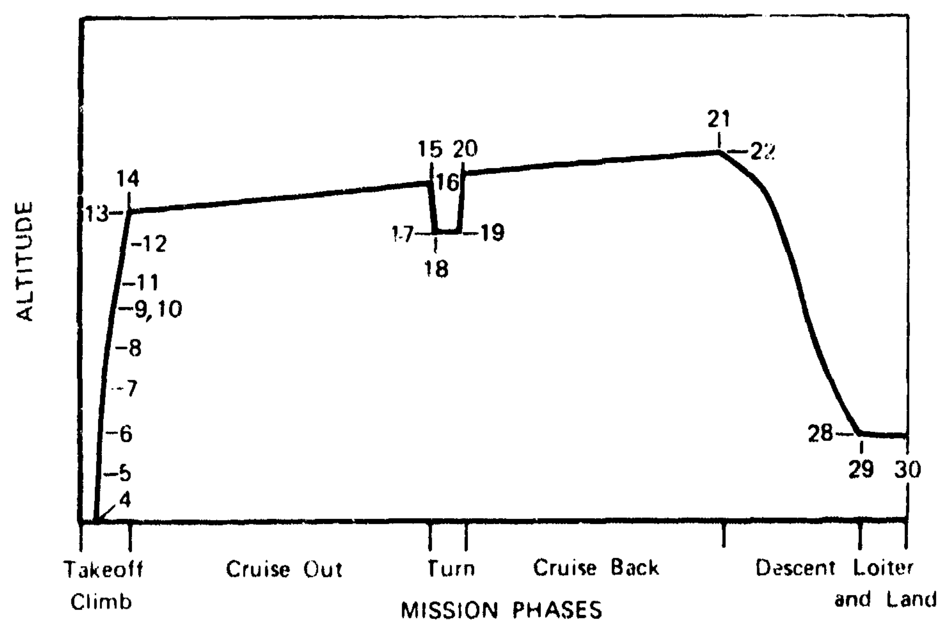


Figure 99. STRJ334B Thermal Analysis Computer Program Mission Altitude Coverage

Other typical operating conditions were studied in addition to those of the baseline mission to determine the most severe operating temperatures that might be encountered by fuels and lubricants. The subsequent paragraphs discuss (1) temperature profiles for the baseline mission, (2) component temperature profiles for the highest fuel temperature conditions of the flight envelope at Mach 4+ cruise at alternate interface temperatures, (3) localized lubricant "hot spot" temperatures, (4) maximum Mach maneuvers with transiently low fuel flow, and (5) flight envelope surveys.

1. STRJ334B Mission Temperature Profiles

Cruise flight speeds above Mach 4 result in environmental temperatures above 1200°F, imposing significant cooling loads for the aircraft and engine. Fuel is the only available cooling medium, and it is limited in total quantity to that required for engine consumption. A plot of fuel temperature vs mission time for fuel at the ramjet burner nozzle (the maximum temperature), engine pump inlet, and aircraft tank is shown in figure 100. The fuel tank temperature profile is estimated from environmental heating effects during cruise and internal absorption of the aircraft heat load subsequent to the start of descent. An estimated aircraft systems cooling load including aerodynamic heating, avionics, cabin air) of 14,000 Btu/min (7,000 Btu/min per engine) results in the temperature difference between the tank and pump inlet temperatures. The maximum fuel temperature, occurring at the ramjet fuel nozzle, is shown to be 515°F for the brief period when fuel flow is reduced at cruise Mach number to initiate descent.

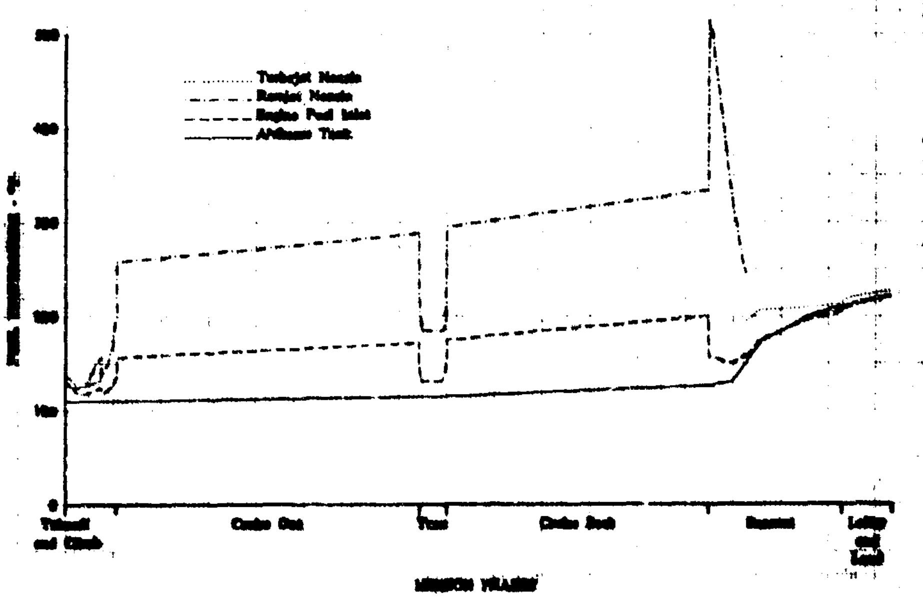


Figure 100. STRJ334B Fuel System Temperatures During the Mission

Maximum lubricant temperatures occur from environmental and internal heating in the bearing compartments of the STRJ334B engine. Figure 101 shows the profile of bearing discharge temperature throughout the baseline mission. A peak temperature of 385°F is encountered during maximum thrust settings for takeoff. Because lubricant heat load is low for descent and since it is cooled by main fuel pump discharge flow, which is only a few degrees higher than the pump inlet temperature shown in figure 100, there is not a high peak lubricant temperature for descent. Figures 102 and 103 show mission profiles of lubricant flows and lubricant heat loads, indicating the low flow and high heat load at takeoff contributing to the maximum temperature.

2. STRJ334B Component Temperature Profiles

Mission temperature profiles in the previous section may not include the highest temperatures that could occur at flight conditions within the aircraft and engine capability, but not included in the baseline mission. Additionally, other tank temperature and aircraft heat load conditions could be encountered. Accordingly, a parametric range of engine inlet fuel temperatures (aircraft/engine interface) were evaluated for maximum Mach cruise at minimum steady-state fuel flow. Figure 104 shows fuel temperature profiles at this most severe flight envelope cruise condition for fuel system components from the engine/aircraft interface to the fuel nozzles. Three alternate interface fuel temperatures of 150, 250, and 350°F were considered, resulting in calculated maximum fuel temperatures of 430, 485, and 550°F, respectively. The fuel tank temperature starting point is arbitrary, and the result would be unchanged by any set of tank temperature and aircraft heat load, resulting in the assumed interface temperatures. Reduced environmental heating and increased specific heat of the fuel as temperature is increased reduce the spread between maximum temperatures compared to the corresponding differences between interface temperatures.

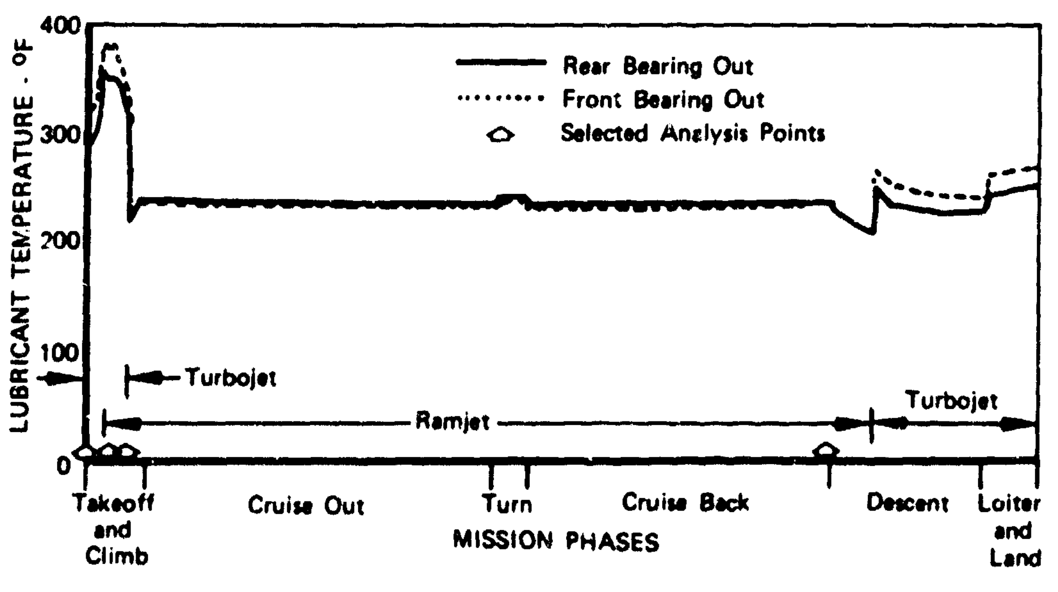


Figure 101. STRJ334B Bearing Compartment Lubricant Temperatures During the Mission

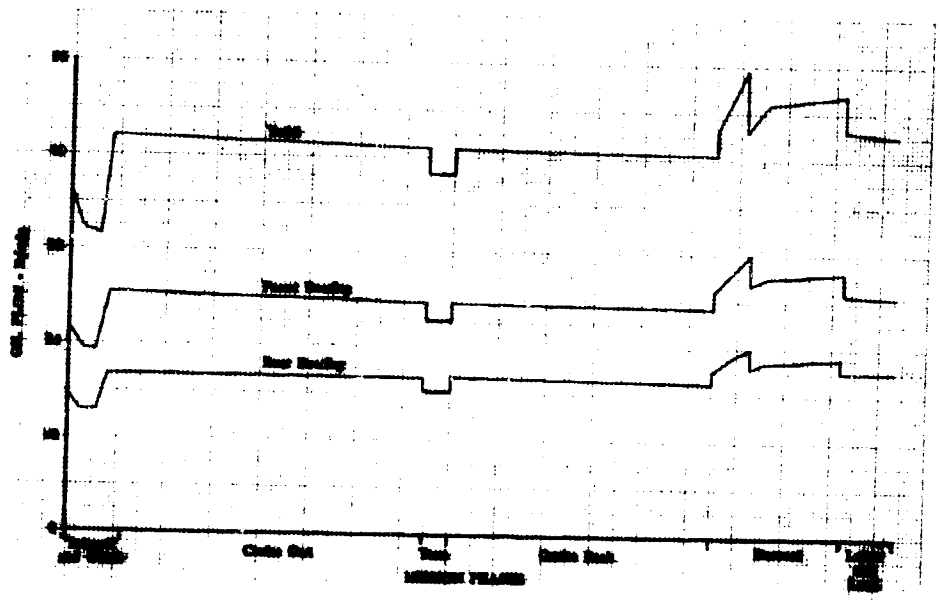


Figure 102. STRJ334B Mission Lubricant Flowrates

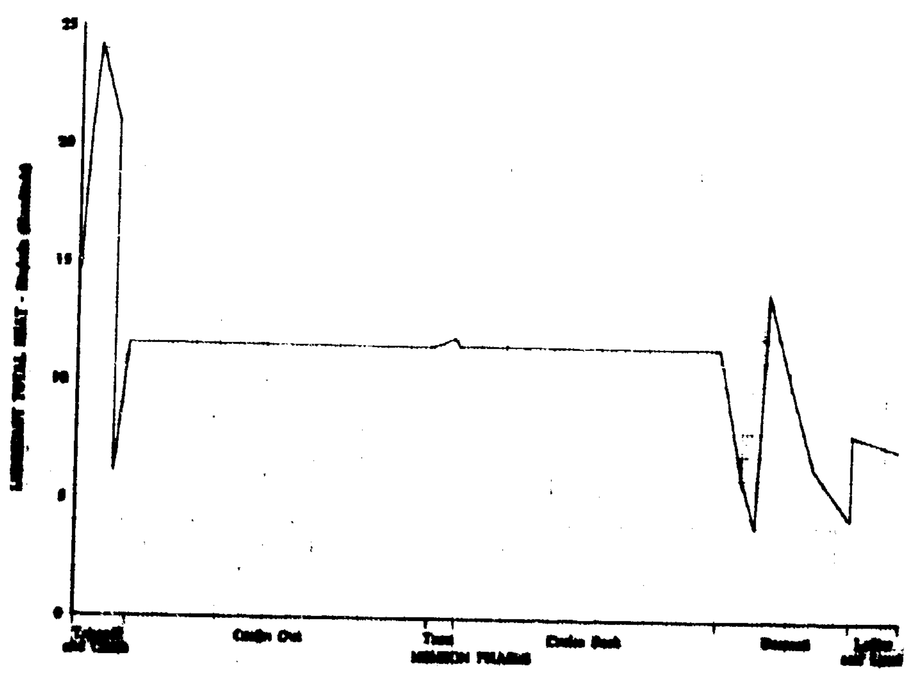


Figure 103. STRJ334B Lubricant Total Heat

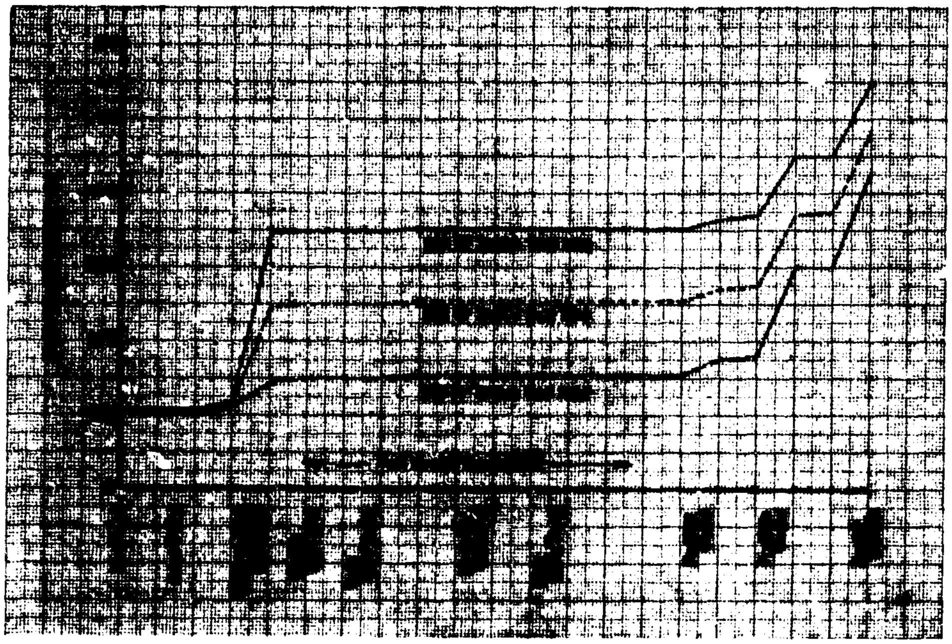


Figure 104. STRJ334B Fuel Stream Temperature Profile
for Cruise Thrust Requirements

Figure 105 shows lubricant temperature profiles at cruise corresponding to 150, 250, and 350°F fuel interface temperatures. Maximum lubricant temperatures are 325, 360, and 450°F, respectively. Therefore, for the fuel flow requirements of the STRJ334B to cover the entire steady-state flight envelope, a 450°F thermal stability lubricant would be required for interface fuel temperature conditions up to 350°F.

3. STRJ334B Lubricant Hot Spots

Hot spot investigations, engine modifications to reduce the hot spots, and analysis of the effectiveness of the revisions were completed on the bearing compartments of the STRJ334B engine. Modifications were made to the bearing compartment designs, and the effectiveness of these revisions in limiting the maximum temperature of both the bulk oil and the lubricant-wetted surfaces was evaluated. The maximum bulk oil temperature was calculated to be 384°F, indicating the possibility that MIL-L-27502 lubricant could meet the mission requirements. However, for the same conditions, the bearing compartments were calculated to have maximum wetted surface temperature of 912°F, above that considered acceptable for any of the candidate lubricants. Redesign of the compartments reduced the wetted-surface temperature to 558°F maximum. This analysis has shown that lubricant selections should consider local heat transfer analysis of components subject to high local heat generation and environmental temperatures, and that selection, based on overall heat balances and bulk oil temperatures, could result in marginal or unacceptable selections of design and lubricants. The bulk oil temperature profiles used in the thermal analysis of the bearing compartments are shown for four representative flight points in figure 106.

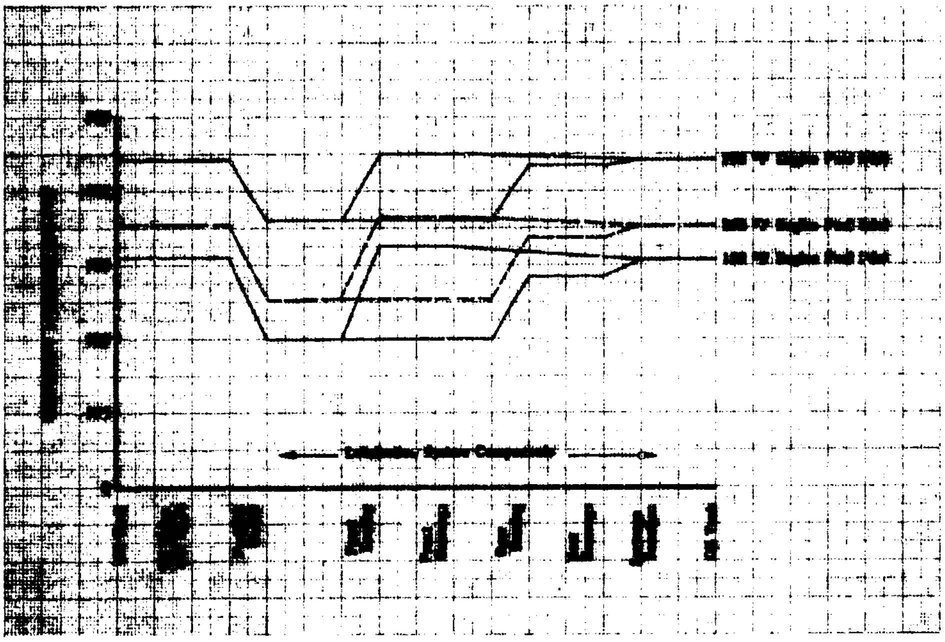


Figure 105. STRJ334B Lubricant Stream Temperature Profile for Cruise Thrust Requirements

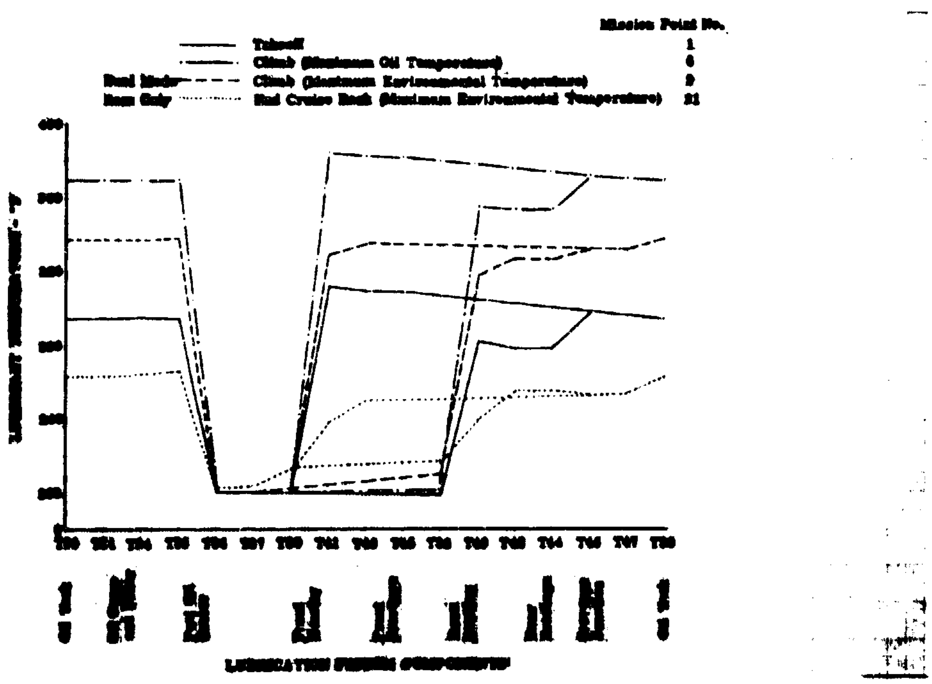


Figure 106. STRJ334B Lubricant Stream Temperature Profiles for Selected Hot Spot Analysis Points

The oil flowrates, bulk oil temperatures, hot spots, and the hot spot temperature reductions achieved with modified designs are summarized in table XVI. In the baseline design, the maximum lubricant-wetted surface temperature was 915°F, occurring on a front bearing compartment seal support that was subject to impingement by seal pressurizing air at the Mach 3+ turbojet operating condition. The lubricant stream temperature profiles, figure 106, showed a maximum bulk oil temperature of 384°F. This occurred during the climb and was located at the front bearing compartment discharge. This low temperature level would be compatible with MIL-L-27502 lubricant. However, the 915°F hot spot revealed by this study could cause coking with any of the candidate lubricants. By modifying the preliminary baseline bearing compartment configuration, the maximum calculated lubricant contact temperature was reduced to 558°F.

Table XVI. STRJ334B Lubrication System Flows and Temperatures

	Front Bearing Compartment				Rear Bearing Compartment			
Mission Point No.*	1	6	9	21	1	6	9	21
Oil Flow, lb/min	21.5	19.2	20.5	24.3	14.3	12.8	13.7	16.2
Bulk Oil In, °F	200	200	206	213	198	201	209	217
Bulk Oil Out, °F	311	384	327	238	282	355	318	239
Baseline Hot Spot, °F	536	847	915	734	444	620	509	395
Location, Node No.	18	18	18	18	72	72	63	63
Revised Design Hot Spot, °F	377	524	558	437	405	554	509	395
Location, Node No.	56	56	56	52	72	72	63	63
Hot Spot Reduction, °F	159	323	357	297	39	66	0	0

*Mission points 1, 6, 9, and 21 are at sea level takeoff, maximum bulk oil temperature, maximum turbojet core engine operating environment, and the highest bulk oil temperature in combination with the maximum ramjet environment.

a. STRJ334B Front Bearing Compartment Analysis

The baseline STRJ334B front bearing compartment was divided into many small nodes for individual temperature calculations, indicated by numbered locations in figure 107. The maximum lubricant-wetted surfaces occurred at each of the seal supports shown by the circled node locations. Calculations revealed temperatures as high as 915°F at the front seal support and 859°F at the rear support. These maximum temperatures occurred during the climb when the turbojet was operating at the core engine maximum of Mach 3+. The rear seal faceplate also showed a hot spot with a calculated temperature of 716°F at the time of maximum bulk oil temperature during the climb. The temperatures of the seal supports were reduced 399°F and 301°F by insulating and modifying the front flange and by adding insulation to the rear flange, as shown in figure 108.

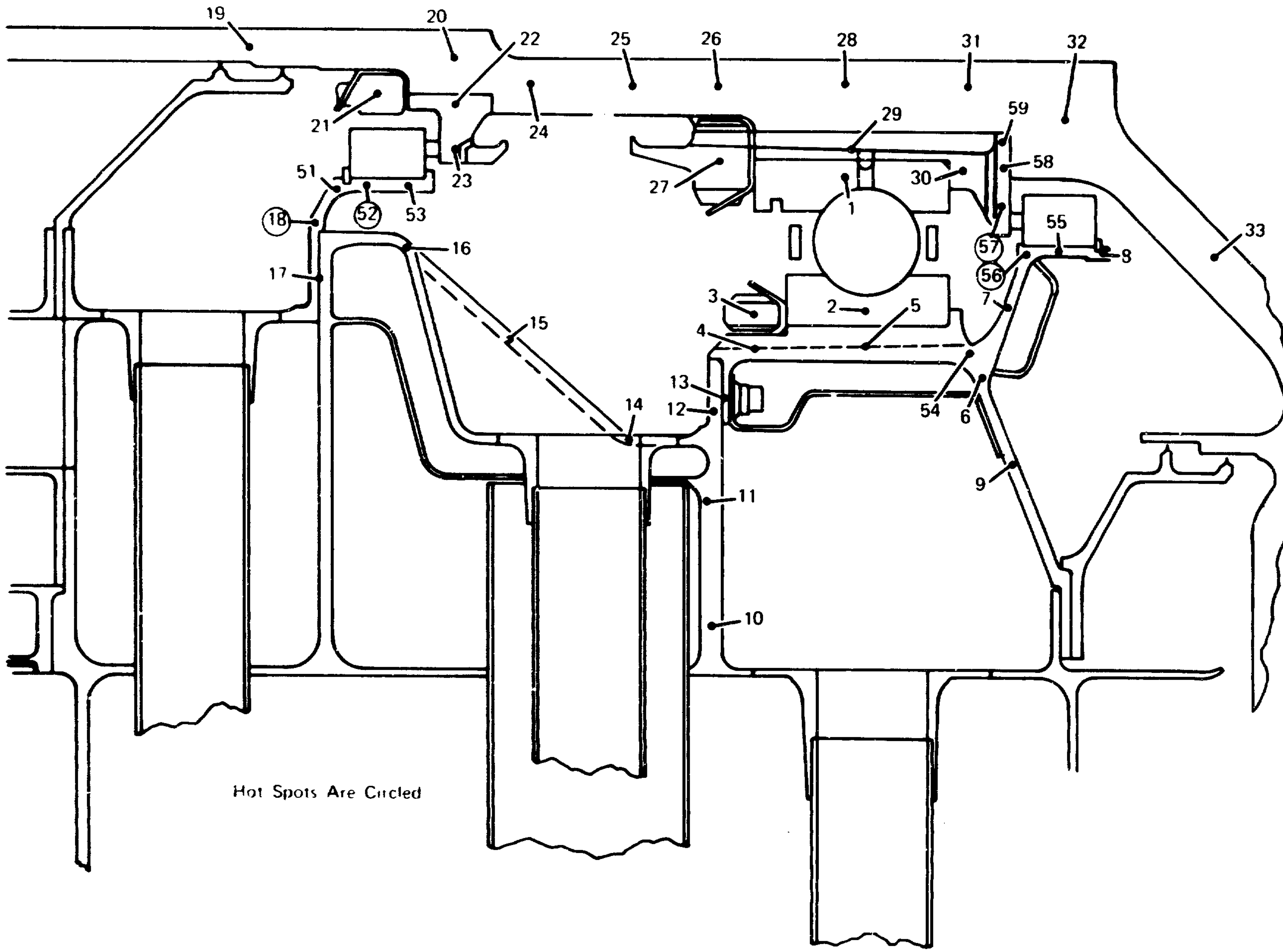


Figure 107. Original STRJ334B Front Bearing Compartment Temperature Analysis Points

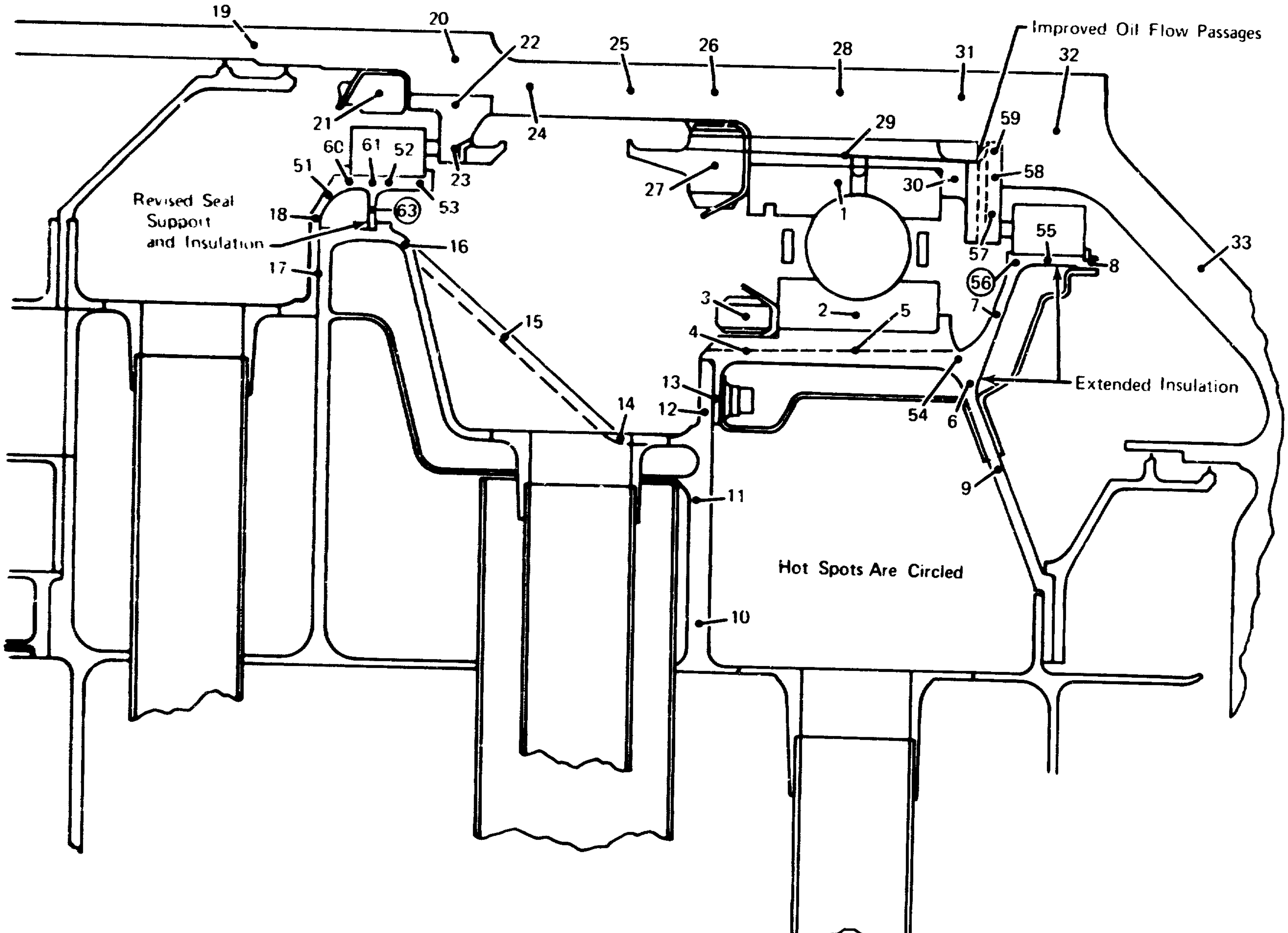


Figure 108. STRJ334B Front Bearing Compartment Revisions and Temperature Analysis Points

The rear seal faceplate temperature was reduced 153°F by providing longer cooling holes near the seal face. With these modifications, the calculated temperatures for each of the component nodes (figure 108) were reduced to levels shown in table XVII. The maximum lubricant-wetted surface for the STRJ334B front bearing compartment was reduced to 558°F at the rear seal support (node point No. 56). This maximum surface temperature still occurs during the climb when the turbojet is operating at Mach 3+.

b. STRJ334B Rear Bearing Compartment Analysis

The baseline STRJ334B rear bearing compartment was divided into nodes for individual temperature calculations, illustrated by the numbered locations in figure 109. The maximum lubricant-wetted surfaces occurred at the seal faceplates shown by the circled node locations. Calculations revealed temperatures of 620°F at the front plate and 567°F at the rear plate when the bulk oil temperature reached a maximum during the climb. The front seal plate temperature was reduced 66°F by reducing the contact area with the relatively hot shaft and by improving the lubricant flow distribution, as shown in figure 110. Also shown is the increase in the cross section of the rear seal plate to increase conductive heat transfer from the oil cooled edge to the heat generating rub surface. With these changes, temperatures were computed for the rear bearing compartment and are shown for component nodes in table XVIII. Maximum lubricant-wetted surface temperatures in the STRJ334B rear bearing compartment are shown to be reduced to 554°F at the front seal plates (node point No. 72). This maximum surface temperature still occurs during the climb when the bulk oil temperature is the highest.

4. STRJ334B Fuel Recirculation to Reduce Transient Temperatures

a. General

The preceding data show maximum fuel temperature of 515°F for mission design conditions; however, in realistic use an aircraft can be expected to perform off-design maneuvers that could cause higher fuel temperatures, in the STRJ334B turboramjet. The "worst case" transient overtemperature that can be anticipated is a sudden power reduction ("throttle-chop") at maximum cruise speed. Profiles of fuel temperature between the aircraft tank and ramjet burner fuel nozzles are compared in figure 111 for this case and the cruise condition. Increased temperatures were computed based on sudden reduction of fuel flow to idle, while cruise heat loads remained unchanged (heat load would start decreasing as the aircraft decelerates). The curve shows the largest increase in fuel temperature for the "throttle-chop" occurs across the aircraft coolers, although increases are significant across fuel/oil and fuel/air coolers. These temperature increases are all reduced by increasing recirculation because this increases fuel flow (cooling capacity) through these heat exchangers.

Table XVII. STRJ334B Revised Front Bearing Compartment Calculated Temperatures

Mission Point No.	1	6	9	21		1	6	9	21
Node	Temperature, °F				Node	Temperature, °F			
1*	403	473	390	233	24*	275	330	311	249
2*	339	406	393	329	25*	262	304	282	239
3*	302	363	358	320	26	279	329	308	257
4*	309	376	380	351	27*	267	308	279	229
5*	339	412	408	348	28*	294	350	324	255
6	432	611	665	527	29*	345	403	345	233
7*	333	444	463	370	30*	351	459	410	246
8	596	903	990	556	31*	322	416	406	282
9	694	1042	1231	1025	32	487	715	744	408
10	497	752	1053	1306	33	700	1054	1239	696
11	502	732	969	1166	51	578	876	999	856
12*	329	420	459	471	52*	355	485	516	437
13	329	419	458	468	53*	325	429	445	376
14*	264	309	303	296	54*	376	502	528	427
15*	258	300	293	286	55	494	730	799	500
16*	313	403	417	374	56*	377	524	558	399
17	645	982	1165	1100	57*	411	563	481	244
18	631	961	1119	998	58*	357	473	424	250
19	668	1005	1150	652	59*	380	526	521	309
20	401	557	567	353	60	445	646	717	612
21	673	1015	1160	662	61	386	540	586	499
22	400	557	533	316	62*	348	470	499	427
23*	351	463	399	250					

*Lubricant-wetted surfaces

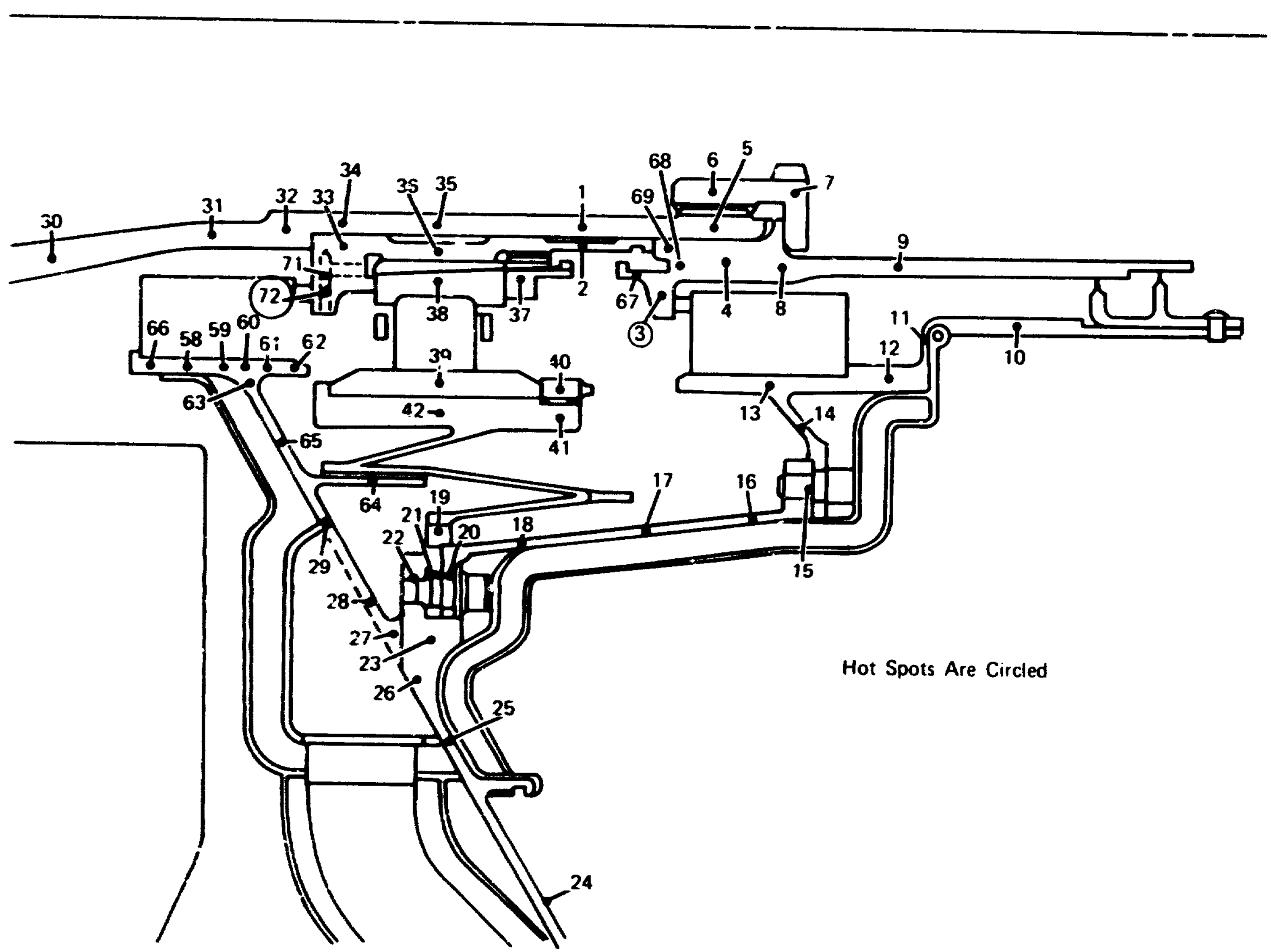


Figure 109. Original STRJ334B Rear Bearing Compartment Temperature Analysis Points

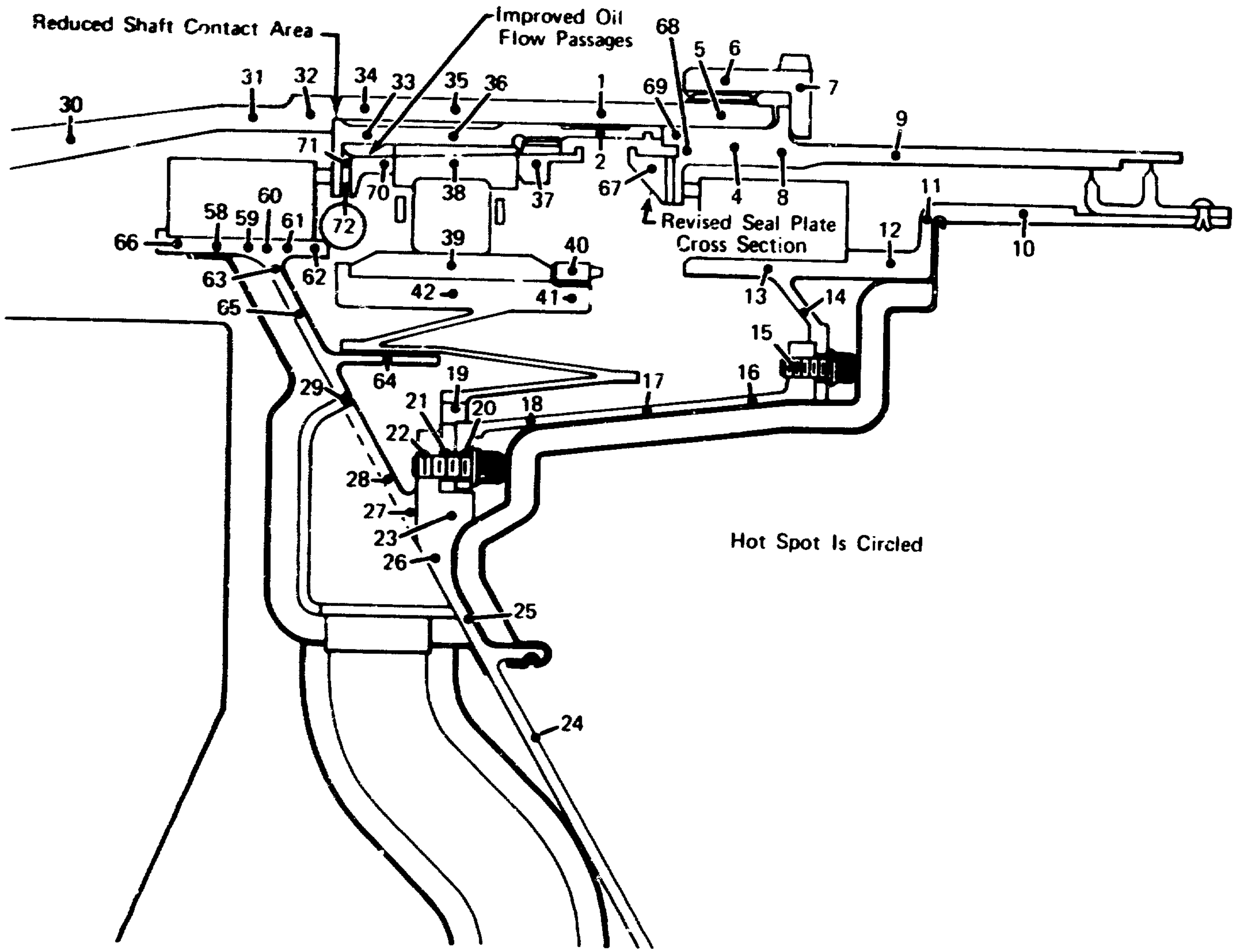


Figure 110. STRJ334B Rear Bearing Compartment Revisions and Temperature Analysis Points

Table XVIII. STRJ334B Revised Rear Bearing Compartment Calculated Temperatures

Mission Point No.	1	6	9	21		1	6	9	21
Node	Temperature, °F				Node	Temperature, °F			
1	296	375	379	283	30	731	1102	1346	1091
2*	254	303	292	240	31	671	1022	1186	807
3*	369	505	428	251	32	597	907	1021	659
4	456	690	685	369	33*	326	437	415	283
5	447	666	674	377	34	500	733	811	520
6	470	702	726	408	35	435	606	661	431
7	538	813	874	484	36*	311	368	322	237
8	549	846	897	485	37*	259	301	277	229
9	714	1082	1287	788	38*	394	458	364	232
10	733	1104	1350	1229	39*	420	529	402	229
11	704	1071	1276	1075	40*	319	386	324	228
12	647	991	1150	894	41*	326	397	330	228
13*	315	418	442	358	42*	399	498	386	229
14*	262	323	324	281	58	594	923	1030	750
15*	253	307	306	274	59	471	710	782	578
16*	248	297	292	261	60	379	546	590	446
17*	247	295	289	257	61*	342	478	508	389
18*	255	309	311	281	62*	299	398	410	323
19*	267	331	342	314	63*	341	477	509	395
20	277	351	372	347	64*	240	279	265	230
21	277	352	373	347	65*	274	351	361	306
22*	279	355	377	351	66	653	1015	1151	850
23	316	424	477	461	67*	287	365	325	236
24	730	1099	1350	1380	68*	348	490	466	286
25	495	731	894	906	69*	327	451	438	281
26	333	454	520	507	70*	304	386	340	241
27*	285	368	399	376	71*	354	482	404	245
28*	266	334	349	321	72*	405	554	434	236
29*	253	308	312	278					

*Lubricant-wetted surfaces

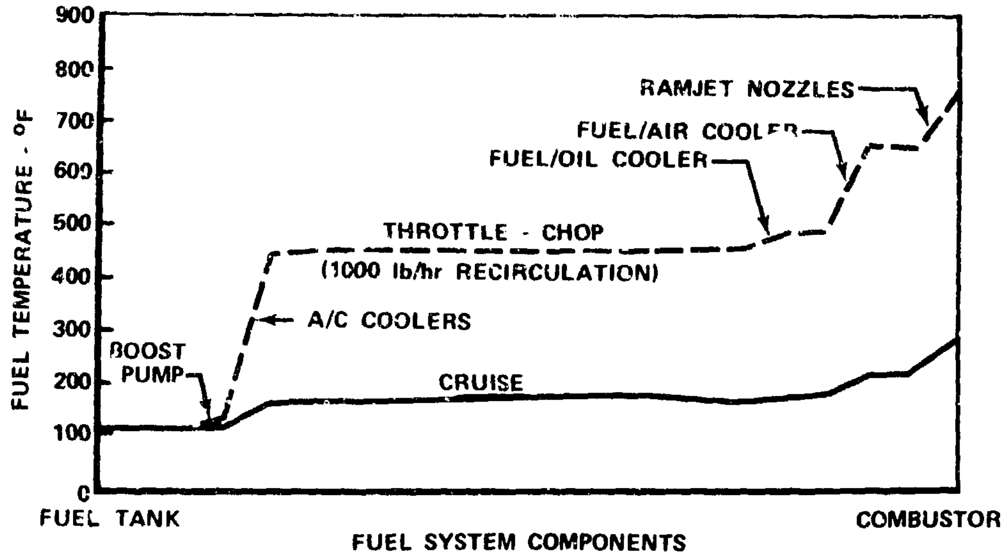


Figure 111. STRJ334B Fuel Stream Temperature Profiles

The effects on maximum fuel temperature (ramjet burner fuel nozzle) are shown for recirculation rates up to 8000 lb/hr in figure 112 and as a function of aircraft tank temperature for a representative aircraft heat load of 7000 Btu/min/engine. With no recirculation, fuel temperature would exceed thermal stability limits of available JP-7 fuel at aircraft tank temperatures as low as 100°F. However, this same fuel should be suitable for use with aircraft fuel tank temperatures as high as 300°F if fuel recirculation of 8000 lb/hr is provided to circumvent the calculated transient fuel overtemperature. High recirculation rates can only be used as a solution to transient overtemperature because fuel temperatures in aircraft tanks and in the engine would soon exceed allowable limits with continuous high recirculation. Typical heat that could be recirculated to aircraft tanks when the engine is throttled to idle fuel flow at maximum cruise Mach number was computed as an example and is shown in figure 113 for the conditions of 200°F fuel in aircraft tanks, a range of aircraft heat loads, and alternate recirculation rates. For conditions of 7000 Btu/min/engine aircraft heat load and 8000 lb/hr fuel recirculation, the amount of heat returned in the fuel recirculated to the aircraft tank can be nearly double that absorbed in cooling the airframe heat load. The temperature of this recirculated fuel at this condition is approximately 400°F, requiring consideration of temperature limits of aircraft structure, fuel vapor pressure, and tank contamination with decomposed fuel.

The effect of aircraft heat loads other than the estimated 7000 Btu/min/engine on the interface fuel temperature and the heat returned to the tank can also be determined from figure 113. For example, a 12,000 Btu/min/engine heat load at 8,000 lb/hr recirculation would result in an aircraft/engine interface fuel temperature of 340°F and a heat load to the tank of approximately 17,000 Btu/min/engine. The resulting maximum fuel temperature at the burner nozzles can be calculated from this recirculation rate and interface fuel temperature to be less than 550°F; these characteristics are plotted in figure 114 to permit estimates of maximum fuel temperatures for other conditions. It can be seen that increasing fuel recirculation rate beyond 8000 lb/hr is reaching a point of diminishing return; but that this amount should be adequate to reduce maximum fuel temperature to levels similar to maximums for steady-state mission flight points at aircraft heat loads

up to 12,000 Btu/min/engine and a fuel tank temperature of 200°F. This permits design of systems and selection of fuels based on mission flight conditions, providing that fuel recirculation can be used to solve conditions of transient fuel overtemperature.

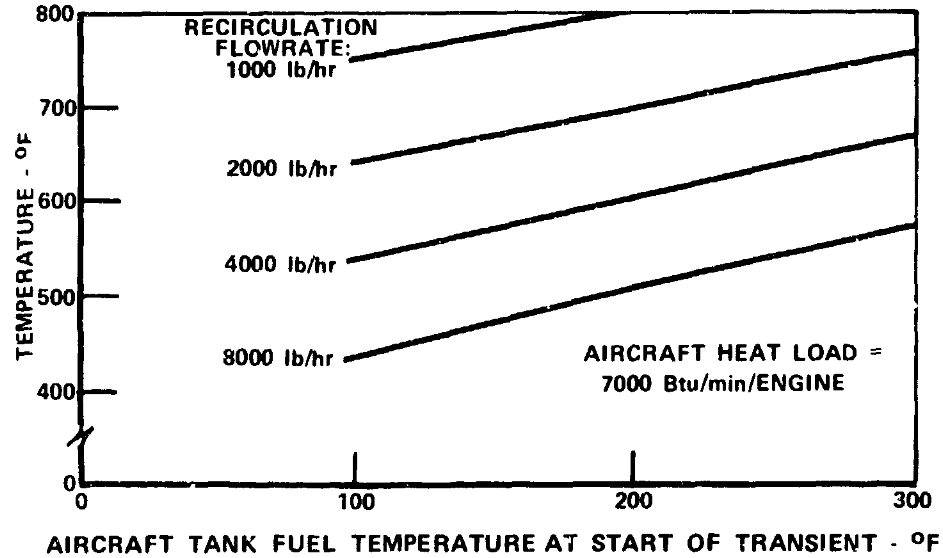


Figure 112. Recirculation Effect on Maximum STRJ334B Fuel Temperature

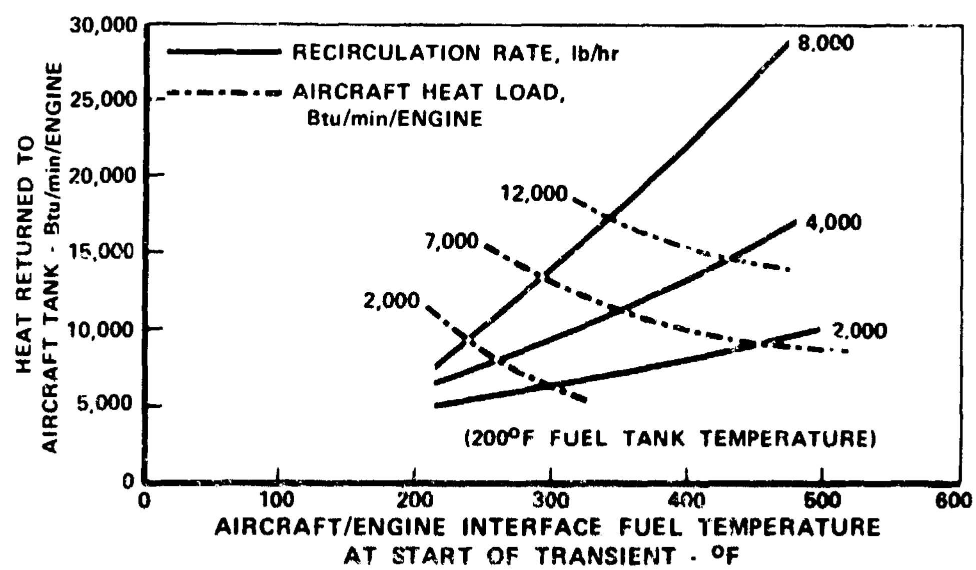


Figure 113. Heat Returned to Aircraft Tank for STRJ334B

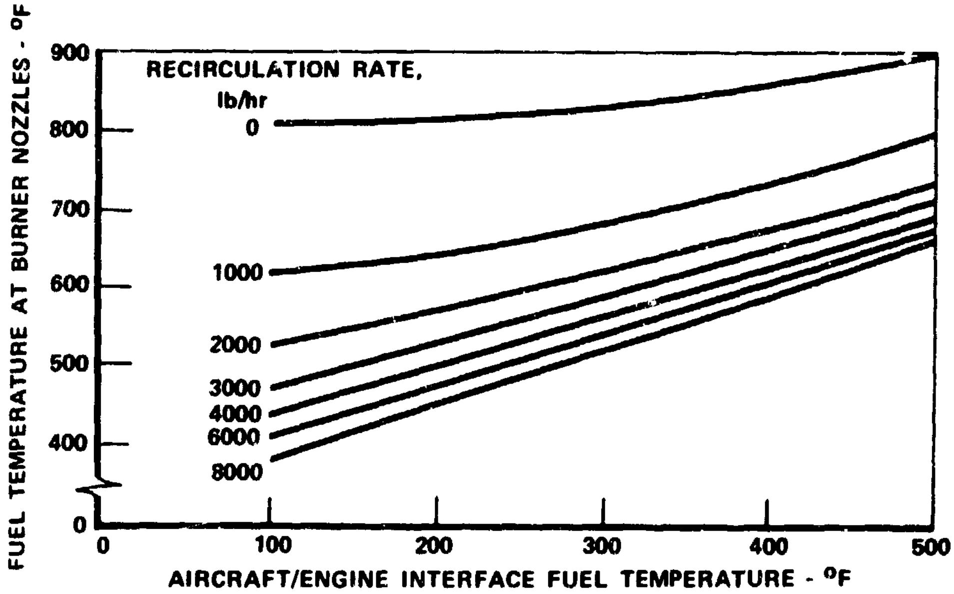


Figure 114. Recirculation and Interface Temperature Effects on Fuel Nozzle Temperature for STRJ334B

Lubricant temperature for the throttle-chop condition and baseline recirculation of 1000 lb/hr of fuel is shown in figure 115. Because the maximum temperature is 520°F, it requires only nominal increase in fuel recirculation to reduce lubricant temperature below 500°F. Additional parametric recirculation data are presented in the following paragraphs for evaluation of alternate conditions from the baseline assumptions.

b. Recirculation Influence on Interface and Recirculated Fuel Temperatures

As can be seen by inspection of the fuel and lubrication system schematic, figure 87, recirculation increases fuel flow through the aircraft heat exchanger, fuel/oil cooler and the core-engine-fuel/air cooler. This increased fuel flow reduces the fuel temperatures throughout the engine fuel system. These effects were computed for parametric ranges of 0 to 8000 lb/hr recirculation and 100 to 500°F fuel interface temperature. Results are shown in figure 114 for the maximum fuel temperature (at ramburner fuel nozzle) and in figure 116 for the temperature of fuel recirculated to the aircraft tank.

An example may clarify the relation of these data to subsequent curves. Assuming that JP-7 fuel is to be used to its 600°F limit, figure 114 shows that for a trial recirculation rate of 4000 lb/hr, a maximum fuel temperature of approximately 360°F could be allowed at the airframe/engine interface. For this temperature and the 4000 lb/hr recirculation rate, figure 116 gives a recirculated fuel temperature of approximately 475°F. Figure 113 will show the heat returned to the tank and maximum airframe heat load that could be absorbed under these conditions for an aircraft fuel tank temperature of 200°F.

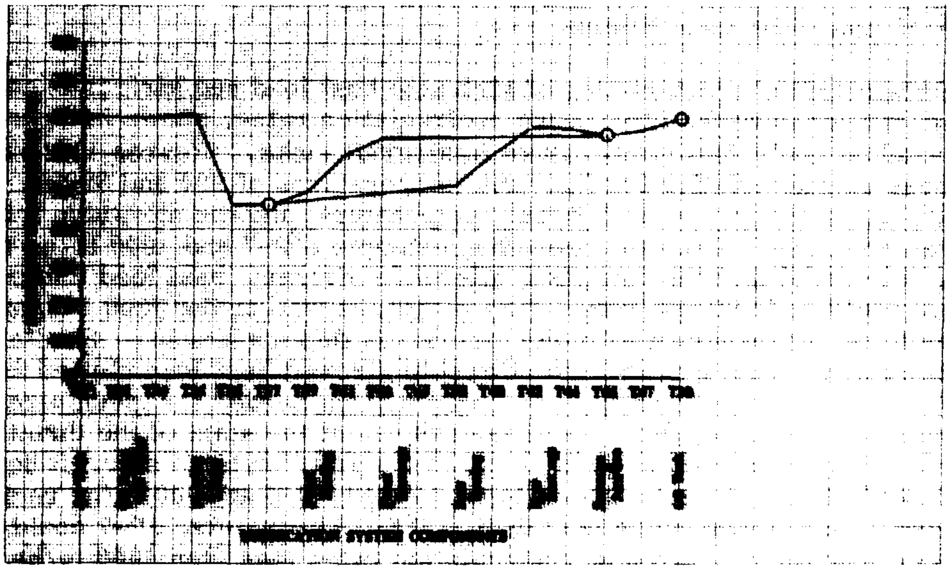


Figure 115. STRJ334B Lubricant Stream Temperature Profile for Throttle-Chop at Cruise Conditions

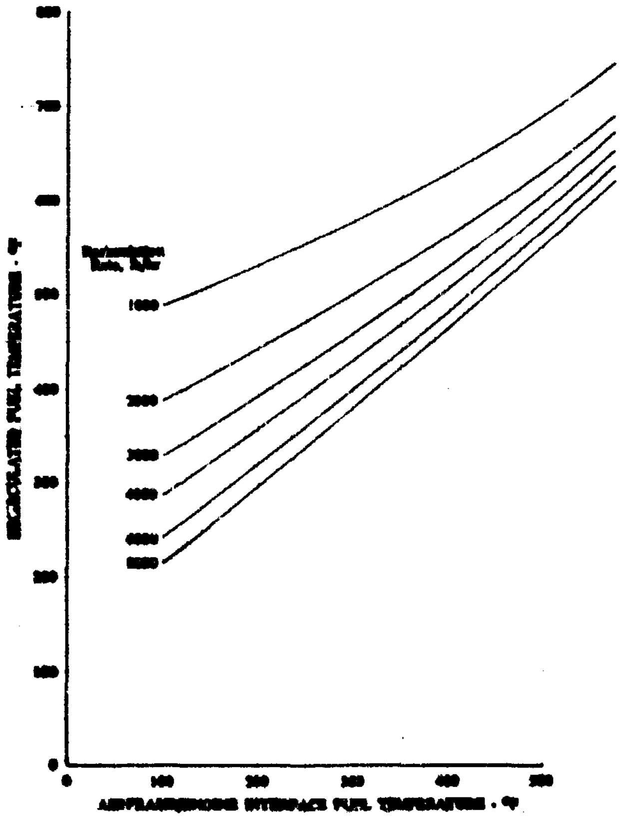


Figure 116. STRJ334B Recirculation and Interface Temperature Effects on Recirculated Fuel Temperature

c. Airframe Heat Load Effects

Parametric characteristics of airframe heat load and airframe/engine interface fuel temperature for alternative recirculation rates, shown in figure 117, were based on 100°F fuel temperature in aircraft tanks. Figures 118 and 119 show these characteristics for fuel tank temperatures of 200 and 300°F. For example, using figure 118 (200°F tank temperature) and the allowable interface temperature of 360°F from the preceding example (JP-7 and 4000 lb/hr recirculation), it is found that the maximum allowable airframe heat load that could be accepted would be 7500 Btu/min. This compares well to the 7000 Btu/min believed to be representative for the aircraft in this application. Similar examples can be generated and the allowable aircraft heat load plotted as in figure 120, showing the type of fuel and recirculation needed for given aircraft heat loads and maximum fuel tank temperatures at the start of the throttle-chop transient. From these data, it is shown that a solution to an aircraft heat input of 7000 Btu/min could be the use of hydrotreated JP-5 at 8000 lb/hr recirculation and aircraft tank temperature less than 175°F. Alternately, JP-7 could be used for higher tank temperatures at recirculation rates less than 4000 lb/hr. These solutions might be further evaluated for acceptability of the temperature of fuel recirculated to aircraft tanks, and the tendency for precipitation of insoluble compounds when heated fuel is mixed with the cooler fuel.

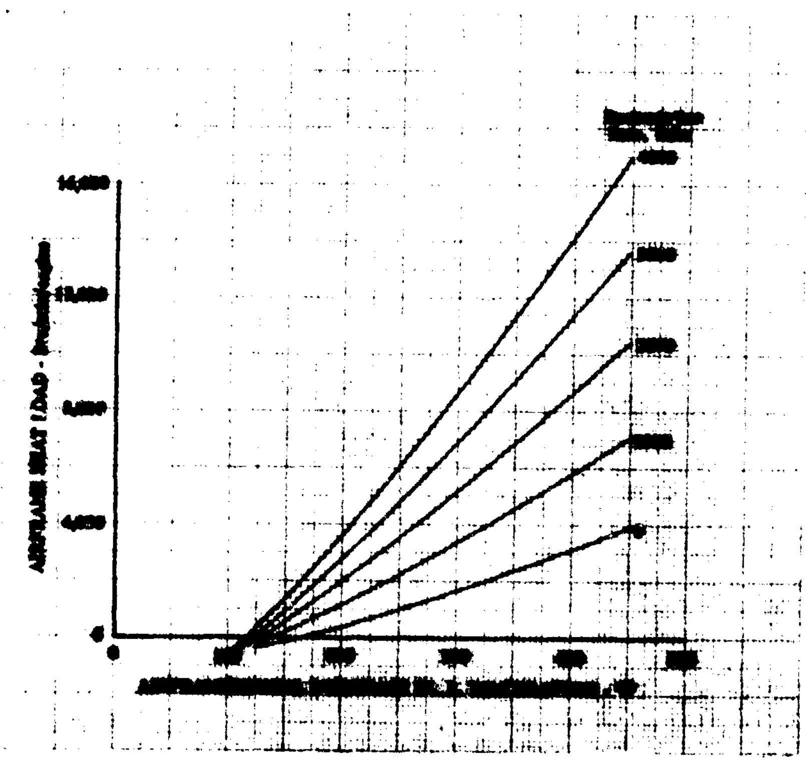


Figure 117. STRJ334B Heat Loads, Recirculation, and Interface Temperatures for 100°F Fuel Tank

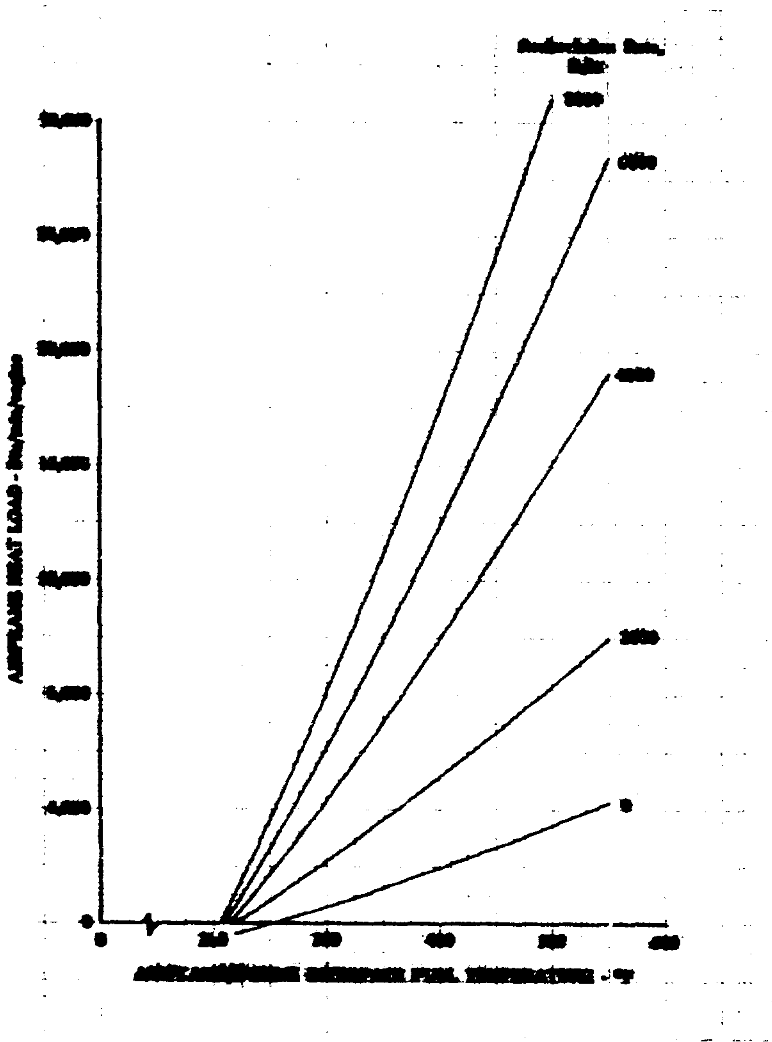


Figure 118. STRJ334B Heat Loads, Recirculation, and Interface Temperatures for 200°F Fuel Tank

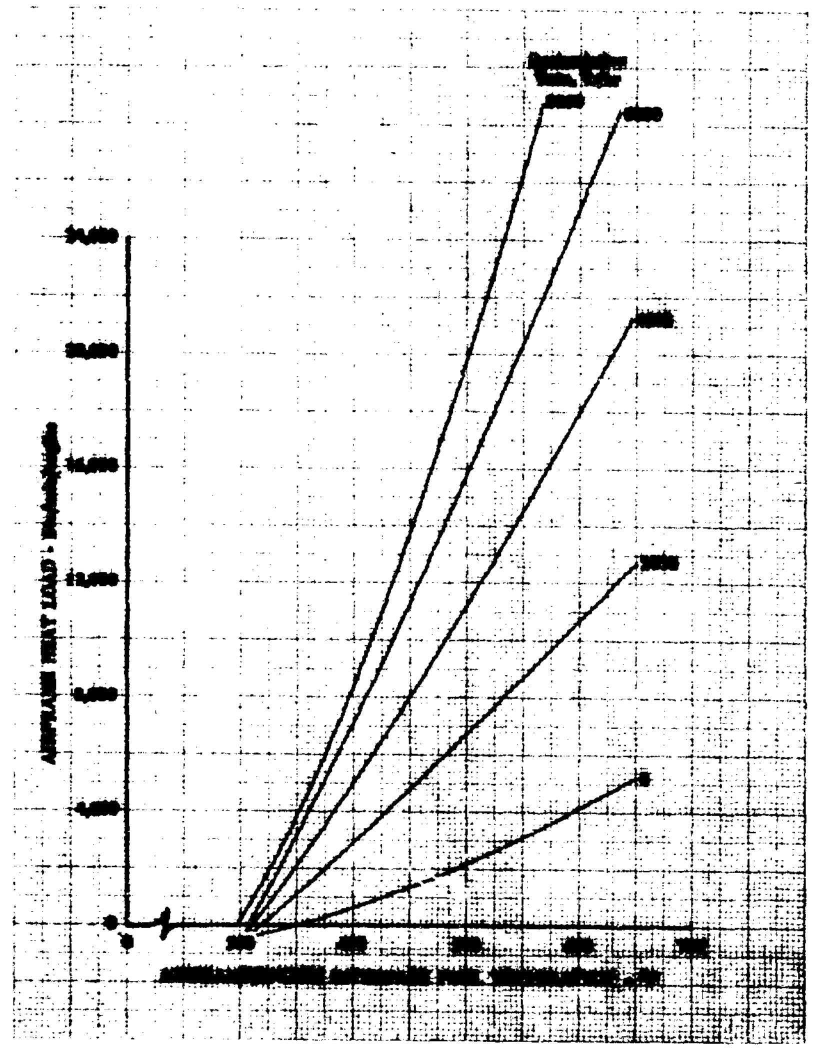


Figure 119. STRJ334B Heat Loads, Recirculation, and Interface Temperatures for 300°F Fuel Tank

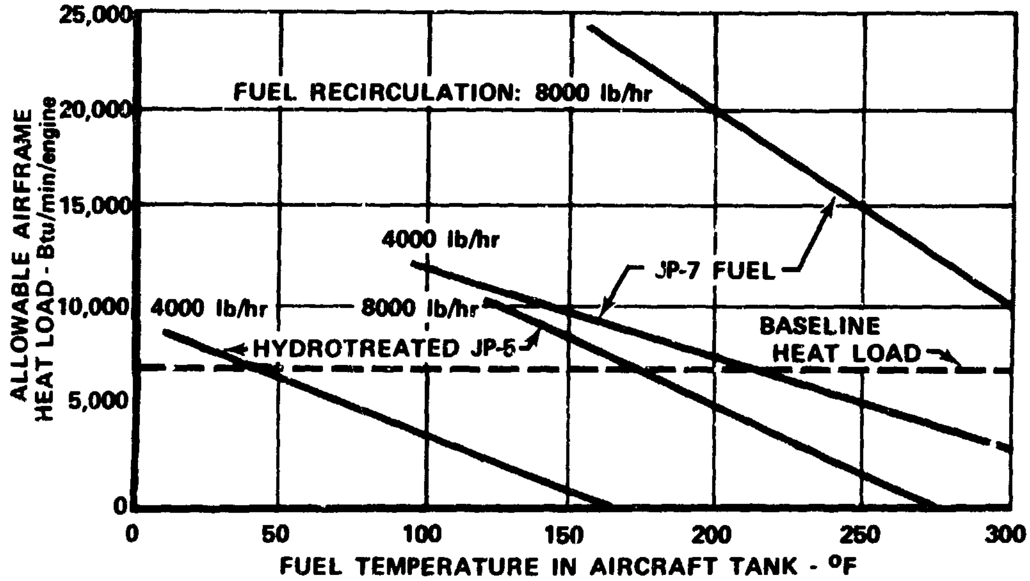


Figure 120. STRJ334B Allowable Aircraft Heat Loads for Alternate Fuels and Recirculation Rates

Figure 121 shows an example of a crossplot of the preceding data to determine the temperature of the recirculated fuel for a particular aircraft heat load (baseline of 7000 Btu/min per engine is used in this example). For the preceding example using hydrotreated JP-5 at 8000 lb/hr recirculation and the limiting case of 175°F tank temperature (from figure 120), a recirculated fuel temperature of 350°F is estimated. This figure shows that the alternate solutions using JP-7, when higher tank temperatures are expected, will lead to recirculation temperatures higher than 400°F, which might result in aircraft tank contamination. Many factors must be considered, including alternate system designs that have different thermal characteristics, in determining the most cost-effective design.

5. STRJ334B Flight Envelope Temperatures

Previous thermal analyses of the fuel and lubrication systems defined thermal conditions for baseline missions and for "worst case" transient maneuvers at maximum Mach number. Temperatures were estimated for candidate fuels and lubricants on the basis of advanced designs and thermal management techniques. However, an aircraft must operate at steady-state conditions beyond those of a specific mission, including all Mach numbers and altitudes within a specified flight envelope. Accordingly, thermal analyses were completed to evaluate fuel and lubricant temperatures and, thereby, define the possible limitations that alternate fuels and lubricants could impose on steady-state engine operation at various altitudes and Mach numbers.

Engine characteristics, including geometry, fuel flow, airflow, lubrication requirements, and the fluid distribution systems, were defined for points representing the complete flight envelopes for the STJ346A and STRJ334B engines. Using these characteristics, the thermal analysis computer program was used to compute fuel and lubricant temperatures for alternate steady-state operating conditions.

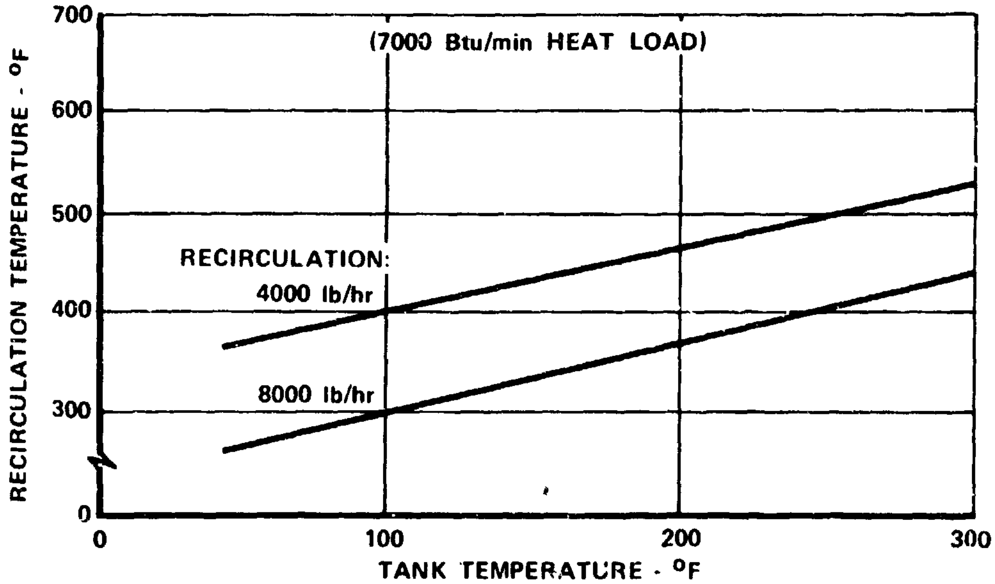


Figure 121. STRJ334B Influence of Tank Temperature and Recirculation Rate on Recirculated Fuel Temperature

Aircraft/engine interface temperature estimates are required in order to estimate maximum engine fluid temperatures at any envelope flight condition.

The higher Mach number requirements and multicycle characteristics of the STRJ334B turboramjet engine, in comparison to the STJ346A turbojet, result in significantly different interface temperature trends. Figure 122 shows the STRJ334B interface fuel temperature characteristics for a 100°F fuel tank temperature and 7000 Btu/min per engine aircraft heat load. Maximum interface temperature of approximately 250°F is estimated on the left-hand side of the envelope. At higher Mach numbers, an interface temperature of 200°F occurs at two altitude conditions. This is caused by aircraft drag (required engine thrust) characteristics. At a constant Mach number, the dynamic pressure decreases with increasing altitude, causing an increased lift coefficient. The induced drag, therefore, increases with altitude; total aircraft drag can be similar at two altitudes for the same Mach number. The similar thrust requirement at two altitudes results in two conditions requiring the same engine fuel flow, causing equal interface fuel temperatures under the simplified assumption of constant aircraft heat load. Figure 123 shows the altitude and Mach number conditions at which 250 and 300°F interface fuel temperatures result from engine fuel flow and environmental characteristics, for a 200°F fuel tank temperature; interface temperature is less than 350°F at any operating point on the flight envelope. Figure 124, for 300°F tank temperature and 7000 Btu/min aircraft heat load, shows interface fuel temperature exceeding 350°F for most of the flight envelope.

Temperatures of fuels and lubricants were computed from STRJ334B engine and environmental characteristics corresponding to 49 steady-state aircraft thrust requirements, representing the flight envelope shown in figures 122, 123, and 124. These were calculated for 150, 250, and 350°F fuel interface temperatures. Calculated ranges of maximum bulk temperatures are summarized in table XIX for these alternate interface fuel temperatures, using 1000 lb/hr recirculation fuel flow.

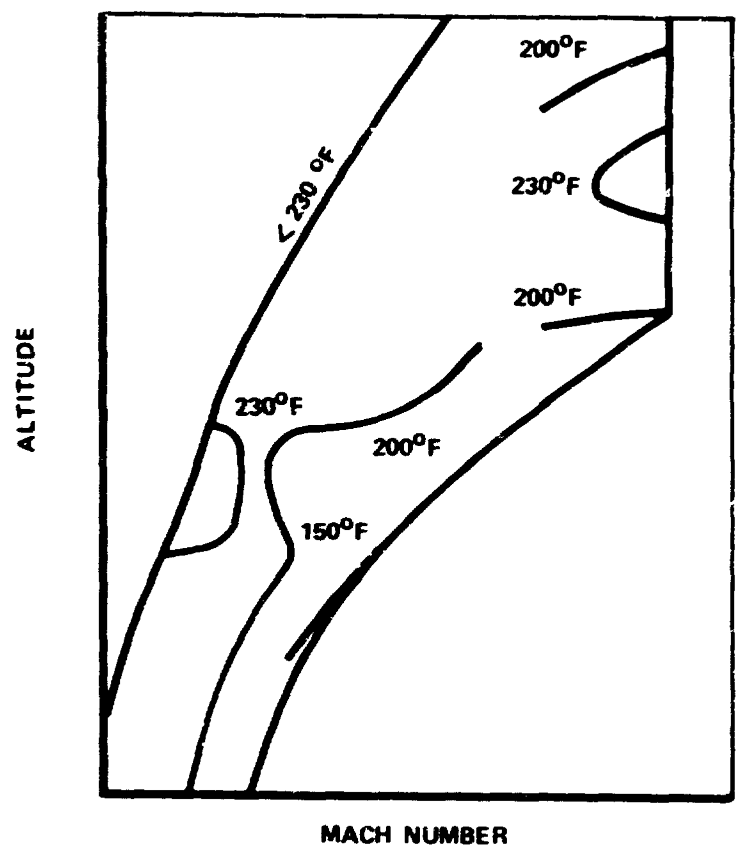


Figure 122. STRJ334B Interface Fuel Temperature for 100°F Fuel Tank

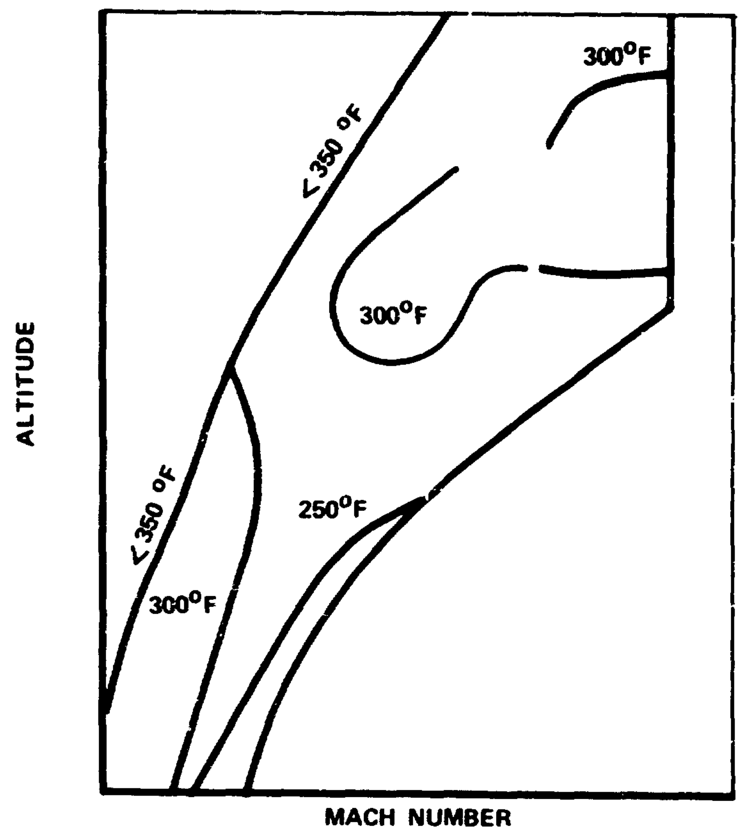


Figure 123. STRJ334B Interface Fuel Temperature for 200°F Fuel Tank

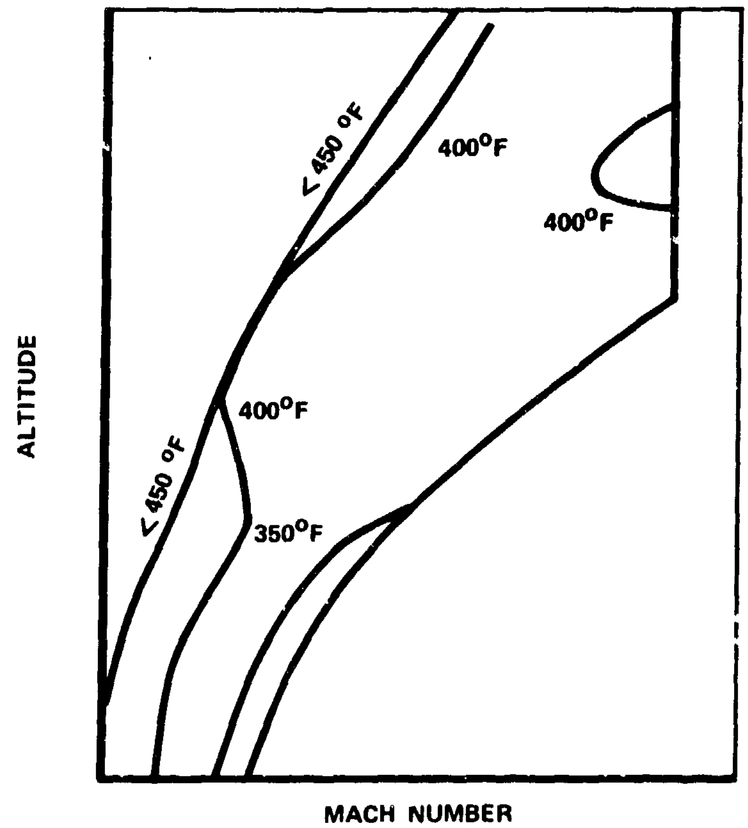


Figure 124. STRJ334B Interface Fuel Temperature for 300°F Fuel Tank

Table XIX. Range of Maximum Fuel and Lubricant Temperature for STRJ334B Flight Envelope

Engine/Aircraft Interface Fuel Temperature, °F	Maximum Bulk Fuel Temperature, °F	Maximum Bulk Lubricant Temperature, °F	Maximum Recirculation Temperature, °F
150	200 to 400	Less Than 425	Less Than 400
250	300 to 500	Less than 425	Less Than 400
350	400 to 550	425 to 500	Greater Than 400

Lines of 325, 350, and 500°F maximum fuel temperatures on flight envelopes indicate possible limiting Mach number and altitude conditions to which the STRJ334B engine could operate with JP-4, JP-5, or hydrotreated JP-5 fuel. These envelope limitations are shown in figures 125, 126, and 127 for 150, 250, and 350°F interface fuel temperatures. The appropriate curve to use for estimating maximum temperature would be based on using an interface temperature selected from curves similar to those shown in figures 122, 123, or 124, but incorporating the actual aircraft environmental heat inputs. Use of JP-5 fuel (350°F thermal stability) can be seen to limit Mach number for 150°F interface temperature (figure 125) and for 250°F interface (figure 126). Figure 127 indicates

use of hydrotreated JP-5, based on a 500°F thermal stability limit, would be marginal at an interface temperature of 350°F, indicating probable choice of JP-7 for maximum capability. The lubricant thermal stability limits can similarly limit Mach number; at 350°F interface temperature, the capability of MIL-L-27502 (425°F) is exceeded within the desired envelope.

The temperature of fuel recirculated to the aircraft system is of concern for interface fuel temperatures of 350°F or higher (figure 128). Above 400°F fuel temperature, the vapor pressure of the fuel and tank contamination can be problems. Figure 129 shows recirculated fuel temperatures for 150°F interface temperature, permitting estimation of fuel recirculation temperature at interface temperatures between those of figures 128 and 129.

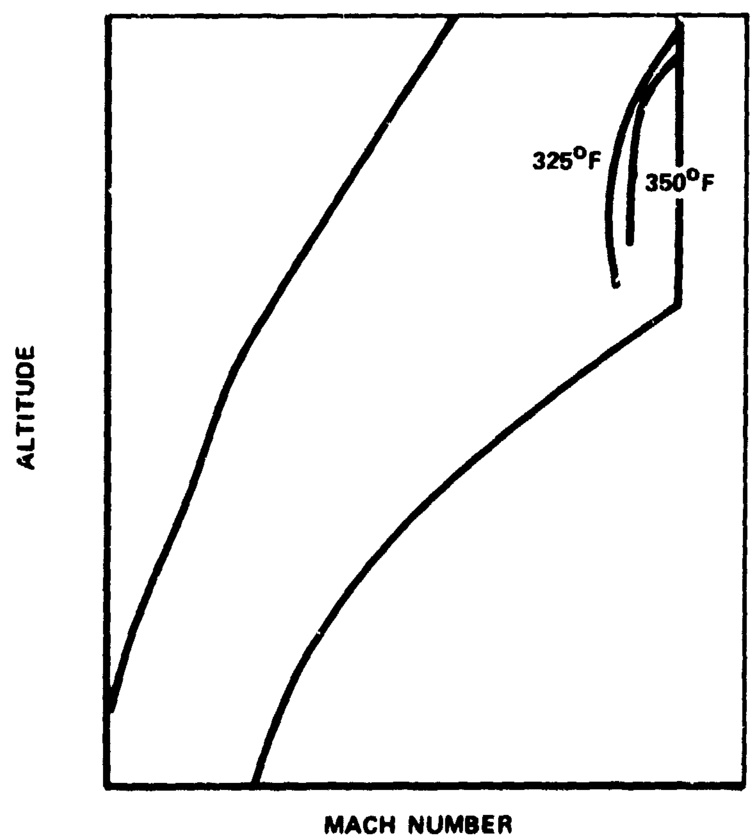


Figure 125. STRJ334B Maximum Fuel Temperature Envelope Limit for 150°F Interface

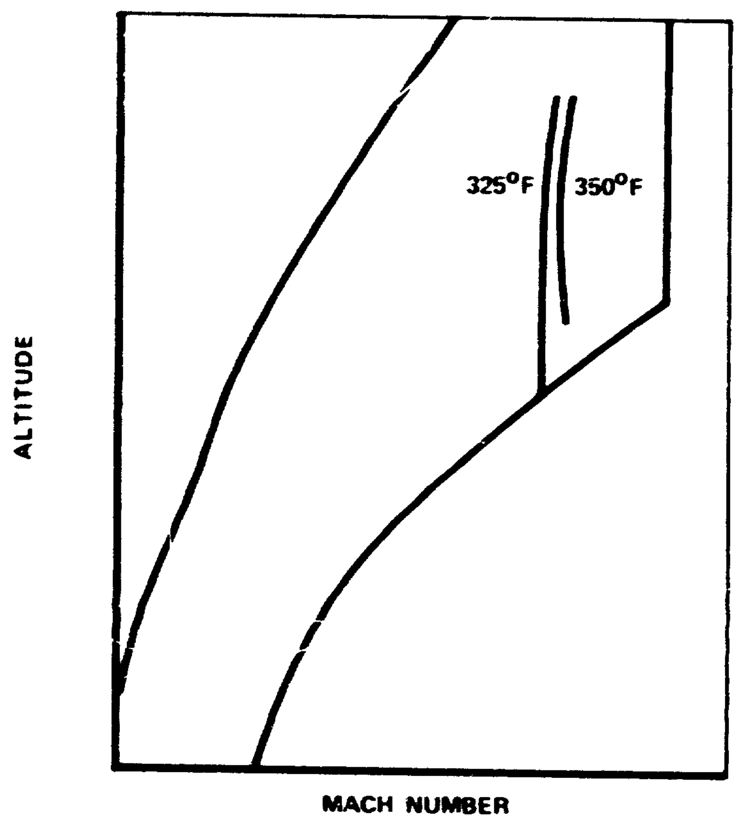


Figure 126. STRJ334B Maximum Fuel Temperature Envelope Limit for 250°F Interface

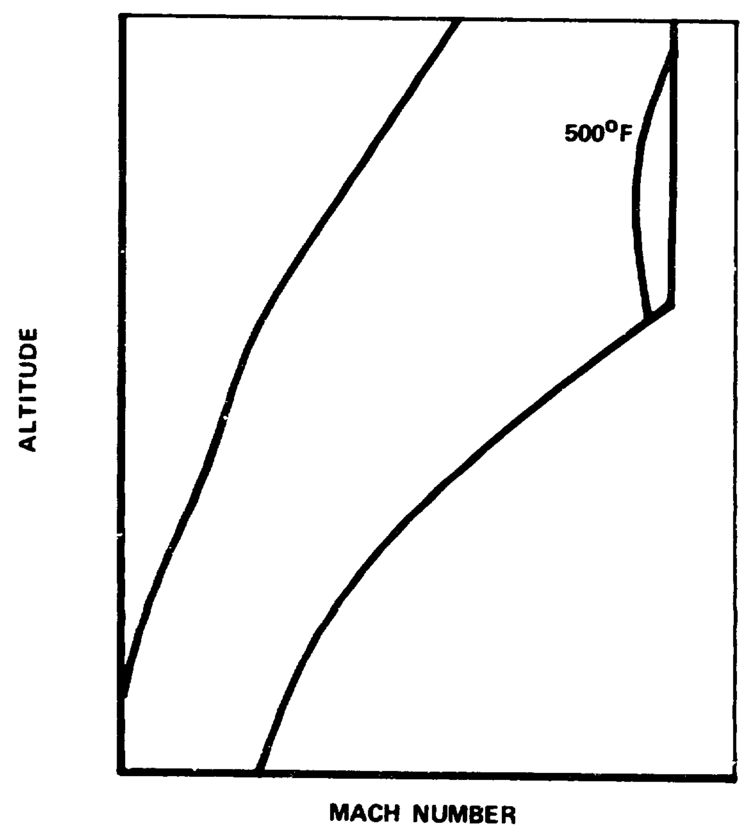


Figure 127. STRJ334B Maximum Fuel Temperature Envelope Limit for 350°F Interface

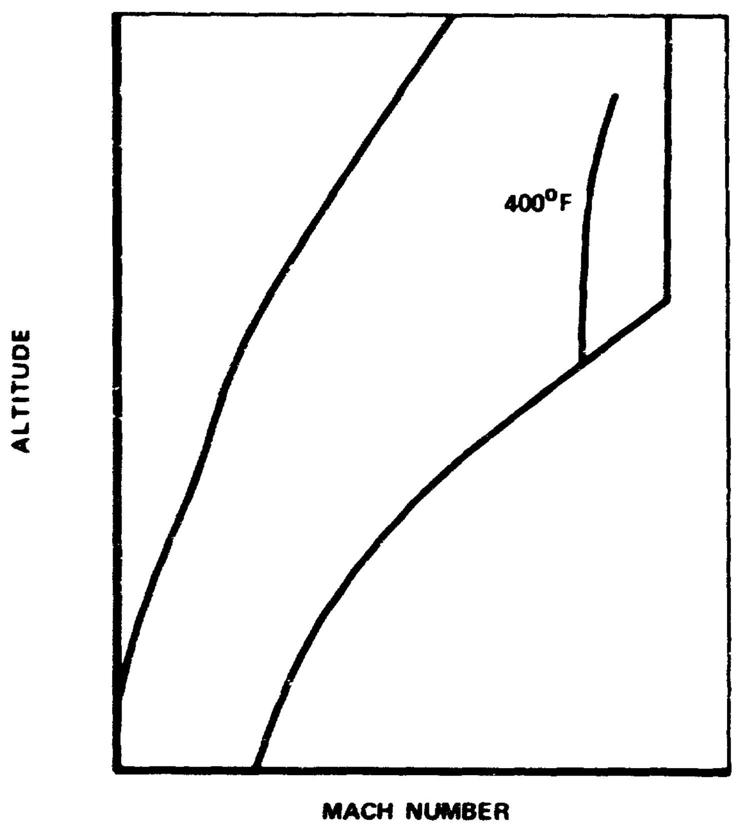


Figure 128. STRJ334B Recirculated Fuel Temperature for 350°F Interface

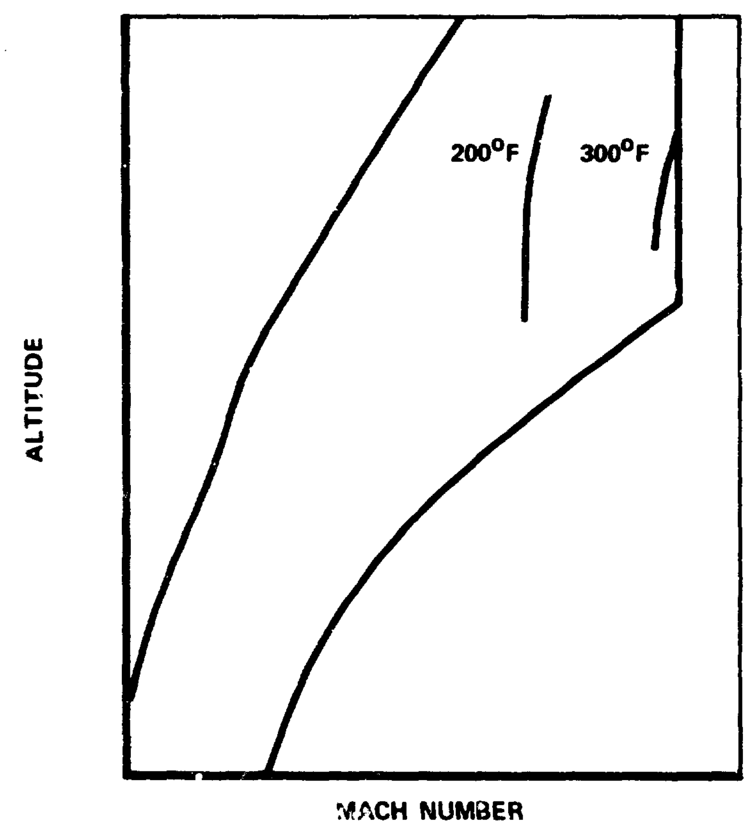


Figure 129. STRJ334B Recirculated Fuel Temperature for 150°F Interface

E. STRJ334B SYSTEM DESIGN INFLUENCES

1. Introduction

Several iterations are required to design a fuel and lubrication system, starting with identification of components and their arrangement. Analysis of the performance characteristics of the system is performed to identify problem areas, and the initial design is modified to begin the next iteration. Iterations on the baseline systems resulted in modifications to the STRJ334B engine system, including addition of a cold oil bypass, thermal shielding of the ramjet fuel nozzle manifolds, and redistribution of lubricant flow. Excessive fuel temperatures relative to all other mission conditions were shown to result for the transient maneuver or turn condition when engine power is reduced to minimum at high Mach cruise conditions. A modified turn maneuver was analyzed that could eliminate this condition for the baseline mission; however, the design should also be suitable for alternate missions and flight maneuvers. Accordingly, fuel recirculation was shown to be a viable and preferred solution (paragraph D.4). Modifications to bearing compartments to reduce temperatures of oil-wetted-metal surfaces were described in paragraph D.3. Fuel distribution systems were modified in accordance with current Air Force contract studies of ramjet combustors. None of the modifications studied introduced significant weight, performance, or operating limits that influenced the capability to meet the Mn, altitude, or range requirements of the baseline mission. Their influence was to reduce maximum fuel and lubricant temperatures, thus contributing to operating economy by reducing requirements of fuels and lubricants and by reducing maintenance and extending life.

2. Optimum STRJ334B Lubrication Distribution

Computations for the baseline fuel and lubrication systems for the STRJ334B engine showed that the oil discharge temperature from the front bearing compartment was significantly higher than the discharge temperature from the rear bearing compartment. Figure 130 shows the required oil distribution during the missions and the degree of variation that would be required for continuously balancing the bearing compartment oil-out temperatures of the STRJ334B engine.

For engine thrust levels established by the requirements for steady-state aircraft operation, figure 131 shows the calculated oil distribution to balance the bearing compartments oil discharge temperatures for 49 points in the STRJ334B operating envelope. On the basis of the mission and operating envelope evaluations, the front bearing compartment oil flows were increased as shown in table XX.

Lubricant stream temperature profiles, defined by thermal analysis of the baseline fuel and lubrication systems with the revised flowrates, show the improved balance in the bearing compartment oil-out temperatures. With the revised flow distribution, the lubricant discharge temperature spread of the STRJ334B bearing compartments were reduced during the mission, as shown in figure 132.

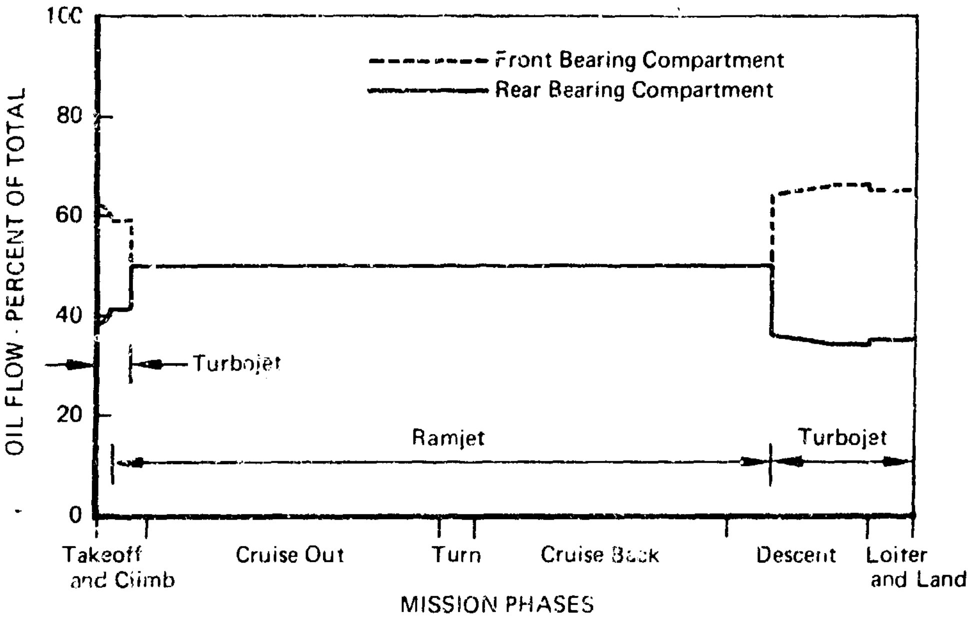


Figure 130. Required STRJ334B Bearing Compartment Oil Flow Distribution to Balance Oil Discharge Temperatures

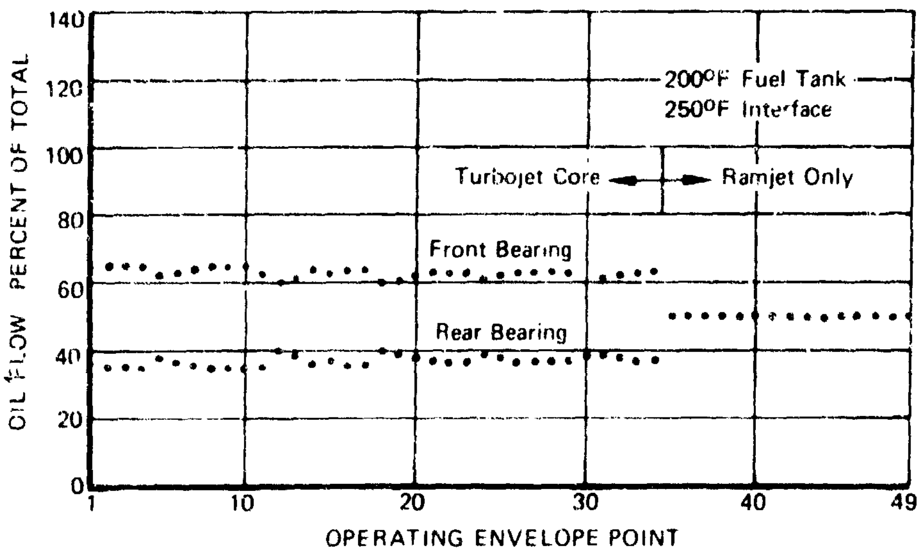


Figure 131. Required STRJ334B Bearing Compartment Oil Flow Distribution to Balance Oil Discharge Temperatures (Operating Envelope at Thrust Required for Steady-State Aircraft Operation)

Table XX. STRJ334B Baseline Lubricant Flow Redistribution

Bearing Compartment	Distribution - Percent of Total Flow Initial Assumption	Revision
Front	50	60
Rear	50	40

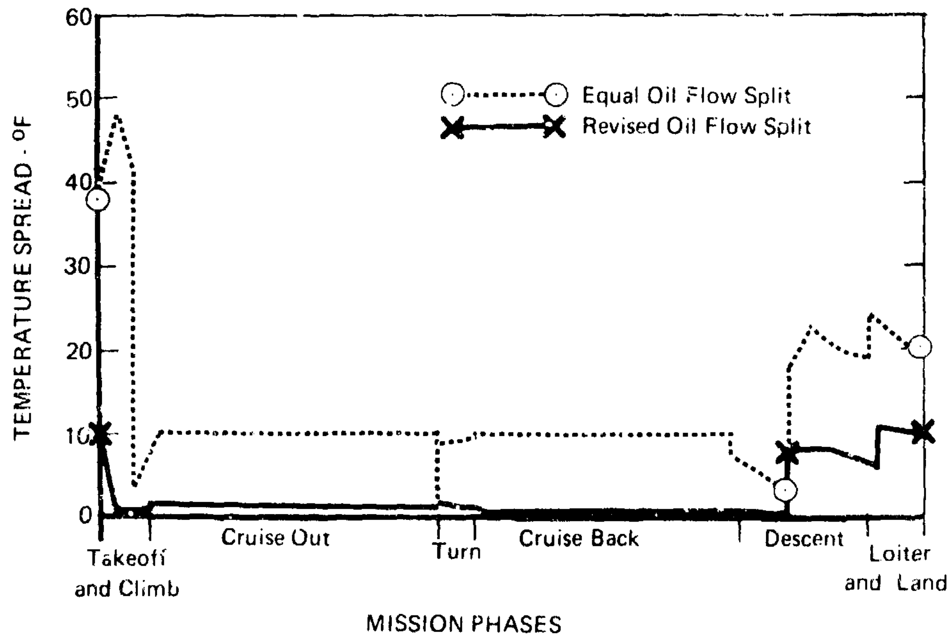


Figure 132. Reduced Lubricant Discharge Temperature Spread of the STRJ334B Bearing Compartments

3. Operating Mode Alternative

Mission evaluations of the baseline fuel and lubrication systems showed high temperature spikes at the start of the turn after the cruise out. The combination of factors causing the sudden rise in the STRJ334B system temperatures included a low engine power setting (low fuel flow) for a short time interval, total airframe heat transferred only to the fuel consumed by the engine, and low heat returned to the airframe (low fuel recirculation). The engine fuel flow was low because thrust was reduced to the minimum for a maximum rate of descent to the turn altitude. The total airframe heat load was being absorbed by the fuel supplied to the engine and resulted in a high airframe/engine interface temperature.

By revising the engine and aircraft mode of operation during the turn, it was possible to change the conditions contributing to the fuel and lubrication system temperature spikes. At the end of the cruise out, the thrust could be increased to maximum and the mission required "g" load turn started. Because the thrust available was lower than the thrust required, the start of the turn was accompanied by a descent to maintain the cruise Mach number. As shown for the STRJ334B engine in figures 133 and 134, this change in the fuel flowrates during the first part of the turn resulted in the elimination of the fuel system high temperature spike.

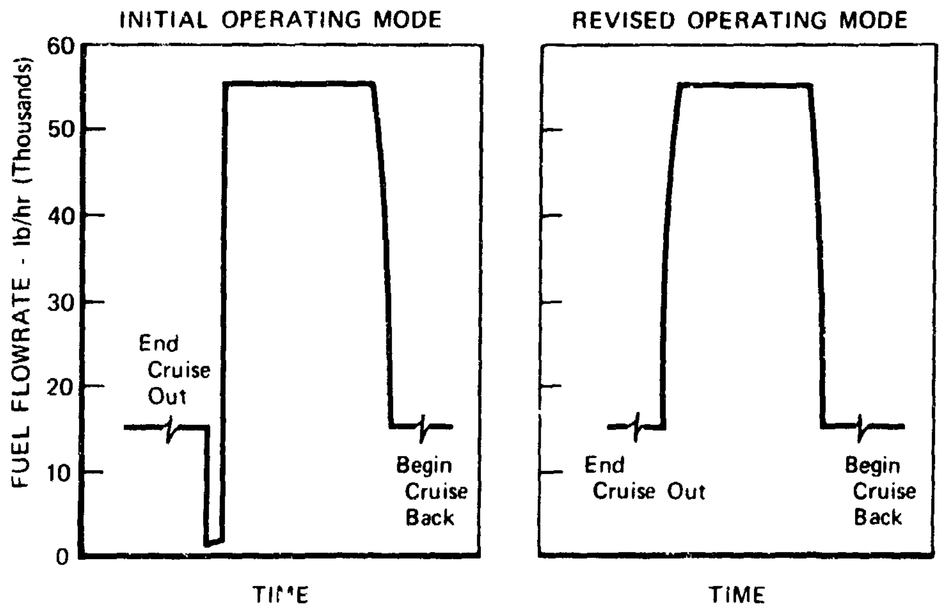


Figure 133. Influence of Mission Turn Operating Mode on the STRJ334B Fuel Flowrate

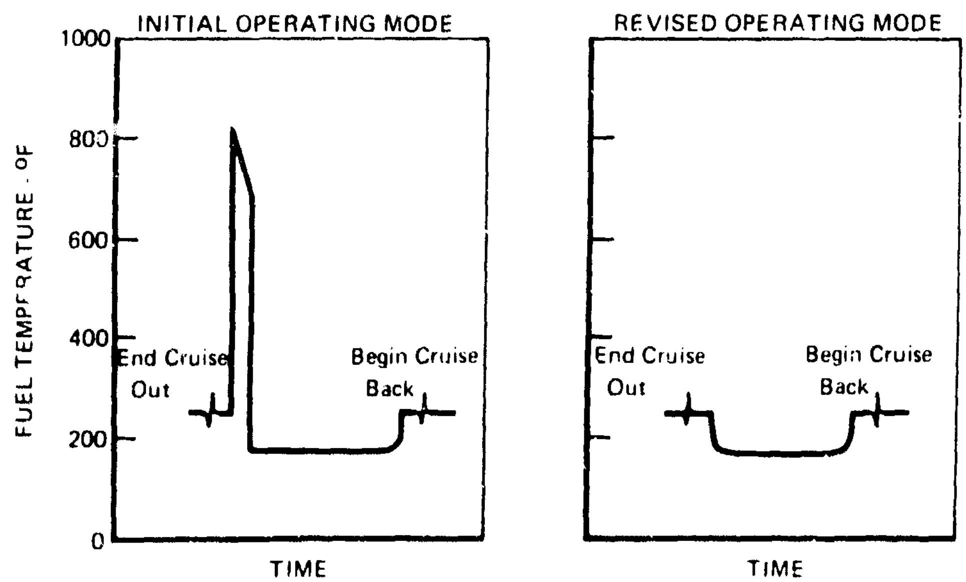


Figure 134. Influence of Mission Turn Operating Mode on the STRJ334B Ramjet Nozzle Fuel Temperature

4. STRJ334B Fuel Distribution System

Initial designs for the STRJ334B turboramjet assumed a simplified fuel distribution system for turbojet and ramjet combustors pending later studies under other programs that would improve their definition. Designs were subsequently revised to reflect these more detailed studies of combustor designs, showing a need to increase the number of fuel nozzles to achieve high flow turndown ratios and to adequately distribute the fuel in the combustors. Designs are based on near-term technology as suggested during an AFAPL review of this contract on 30 June 1972.

The turbojet burner fuel nozzles shown in figure 135 alternate between single (nozzle B) and dual (nozzle A) nozzle configurations. The additional spray nozzle on every other support was added to increase the range of the burner temperature rise to that required for the STRJ334B. The supports are short to reduce fuel heating from exposure to compressor discharge airflow conditions. All have a main discharge orifice with spacing based on ATEGG experience.

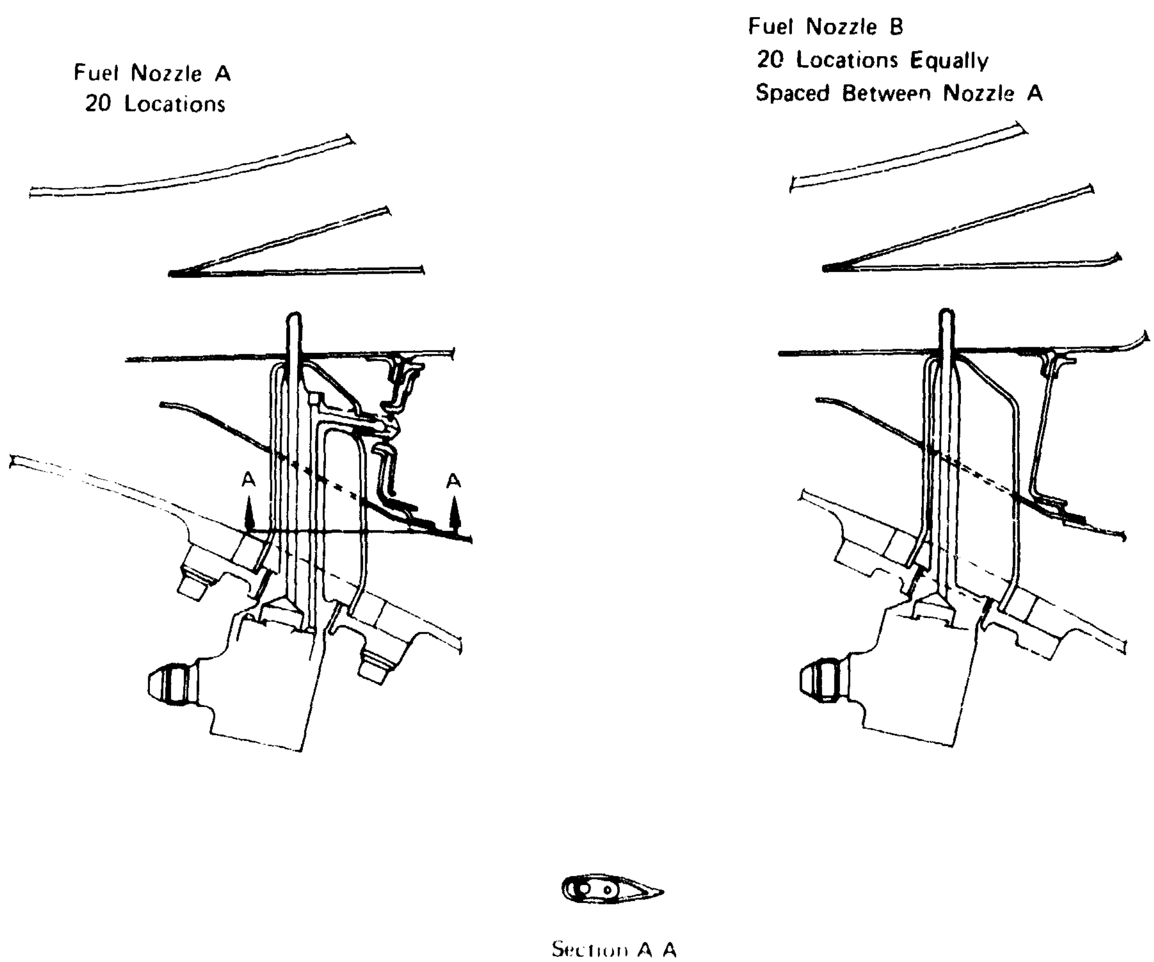


Figure 135. Alternate STRJ334B Turbojet Nozzle Supports Incorporate Dual Systems

The wraparound ramjet fuel system, shown on figure 136, is based on a preburner and ramburner configuration defined in the "Study of Low Pressure Duct Burner," USAF Contract F33615-72-C-1134. The preburner is scheduled only for ramjet operation below 400°F inlet temperature. Above this temperature the preheater nozzles and manifolds are drained. For the mission thermal analysis, at high Mach number climb and cruise conditions, the fuel is distributed in all three sprayring zones. Future rig evaluation of the configuration, under the low pressure duct burner contract, may show a need to reduce the number of burning zones for the part power cruise condition. During the low power descent, the ramjet fuel is limited to the center sprayring zone, so that the local fuel air ratio will be high enough to maintain combustion.

The influence of these fuel nozzle design variations are small for the turbojet section of the STRJ334B engine. Calculated fuel temperature changes are shown in figure 137. For the turbojet part of the system, the greatest effect is a cooling influence of less than 20°F during descent and loiter that comes from ambient effects on added manifold lines.

The long ramjet sprayrings were designed with four inlets per ring to reduce the time that fuel lines were exposed to the scrubbing effects of the hot ramjet airflow. The system shows a temperature increase approaching 50°F as the cruise fuel flow reduces at the end of the cruise back. A potential for lower ramjet sprayring fuel temperatures will be realized if the low pressure duct burner rig program shows that the burning zones could be reduced for the partial power cruise conditions. These fuel nozzle designs, based on current technology, resulted in the turbojet and ramjet nozzle fuel temperatures shown in figure 100 during the mission. The airframe tank and engine fuel temperatures, shown in the same figure, were not affected.

5. STRJ334B Actuation Systems

a. Introduction

The baseline designs for the STJ346A afterburning turbojet and the STRJ334B turboramjet include pneumatic actuation systems for variable geometry similar to those used for the exhaust nozzle on the F100 and F401 engines (air-motor, flexible-shaft, ball-screw actuators). The F100/F401 application proves the capability of this type system for 500°F ambient temperatures and air motor supply temperature of 1200°F. Based on the use of a dry lubricant for the flexible-shafts and ball-screw actuators, this capability could be increased to satisfy requirements of the STJ346A engine. More advanced technology must be developed to use this type of system to accommodate the higher environmental temperatures of the STRJ334B engine. Existing technology could require use of a hydraulic actuation system, adding a significant heat load to the STRJ334B fuel system. To evaluate this possibility, a hydraulic system was defined, and the resulting increases in fuel and lubricant temperature were calculated.

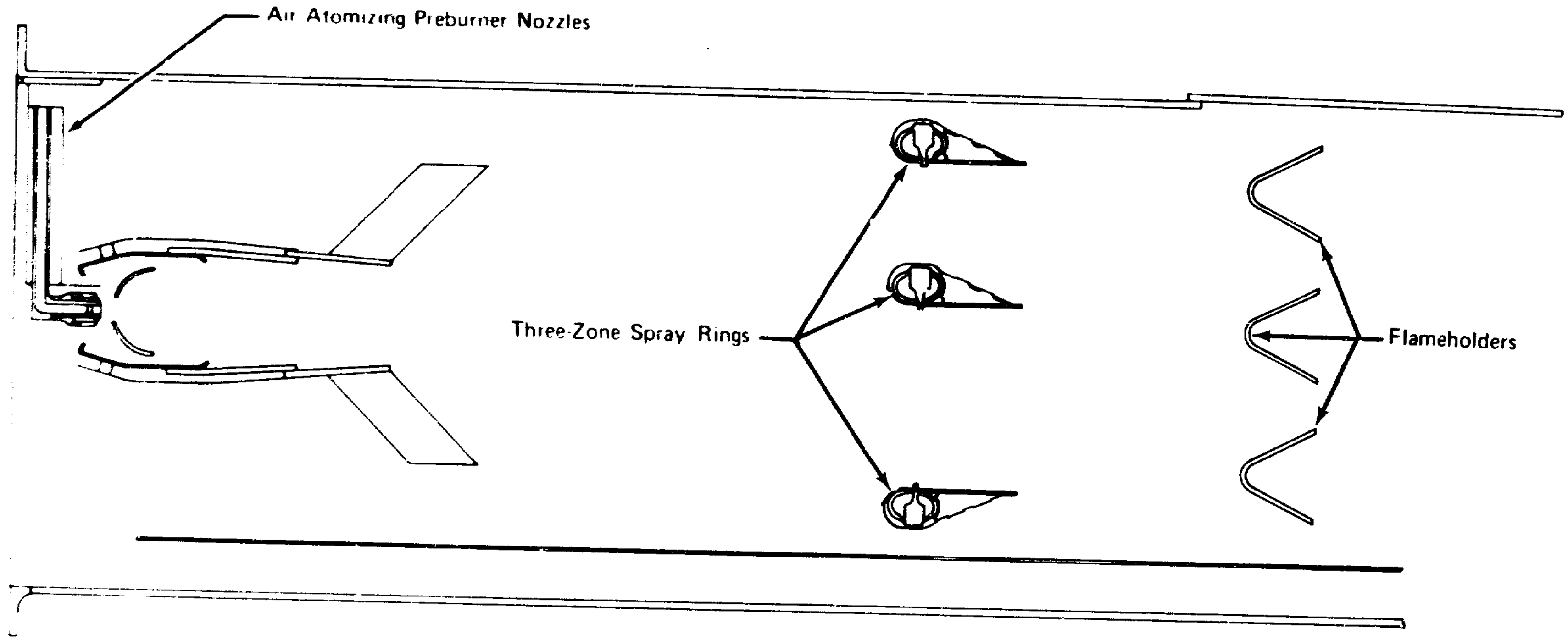


Figure 136. STRJ334B Wraparound Ramburner Fuel Distribution

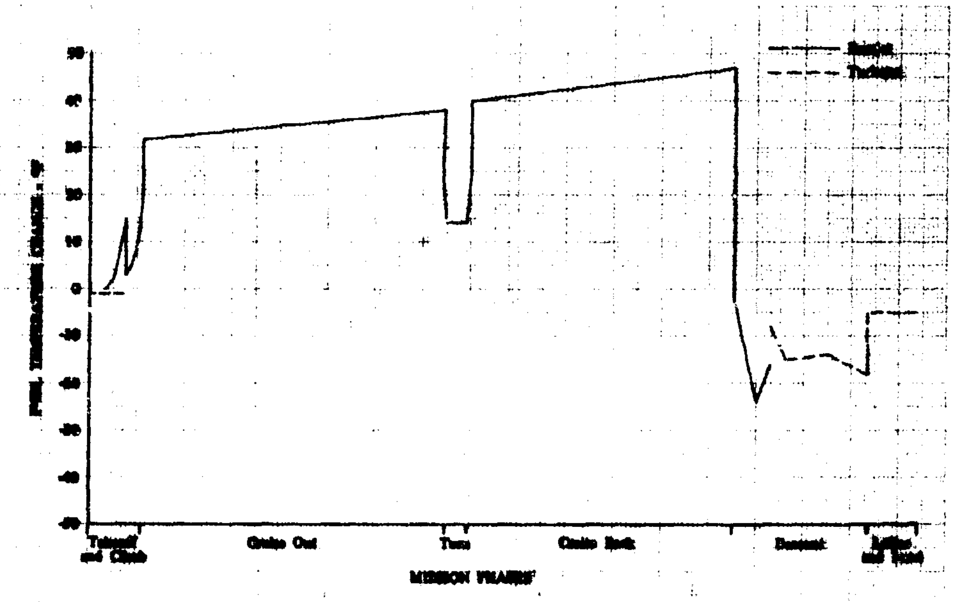


Figure 137. STRJ334B Maximum Nozzle Fuel Temperature Changes Resulting From Improved System Definitions

Actuation systems are required for the STRJ33 lB turboramjet for the start bleed, variable compressor vanes, variable turbojet core nozzle, and ramjet duct nozzle. The baseline design projects advancements in pneumatic actuation designs that would permit their use without fuel cooling in the extreme temperature environment of the STRJ334B engine. Alternatively, hydraulic actuation, using fuel as the working fluid, is a commonly used approach that can be insulated and cooled by continuously circulating fuel (avoiding stagnation of fuel in any part of the system) to achieve operation at the high environmental ram air temperature of 1200+°F. Figure 138 shows a schematic of a hydraulic system for the STRJ334B. System pressure of 3000 psi and maximum flowrate of 25,000 lb/hr were computed based on required actuation forces. This is an open system that is directly connected to the engine fuel system for supply and discharge of fuel. The supply and discharge must be located upstream of fuel pumps so that transient demands of high hydraulic flow to rapidly actuate variable geometry do not upset the closely controlled flow of fuel to the engine. This location is No. 1 of three locations, indicated in figure 139, for fuel cooling of a hydraulic system. Each location was evaluated for its influence on system temperatures, since the objective was to identify representative temperature effects without designing a hydraulic system.

b. Hydraulic System Configuration

A modified engine assembly drawing, figure 140, shows a fully hydraulic actuation system. This system has a separate hydraulic pump that is driven by an air turbine.

In the course of investigating th[illegible] [illegible]aulic system requirements, [illegible] determined that the original nozzle desig[illegible] [illegible]ired very high actuation [illegible] It was decided at that time to redesign [illegible] nozzle to reduce the required actuation force. A balanced-[illegible] [illegible] the JTF22 nozzle, was designed for the STRJ334B that [illegible] [illegible]on requirements.

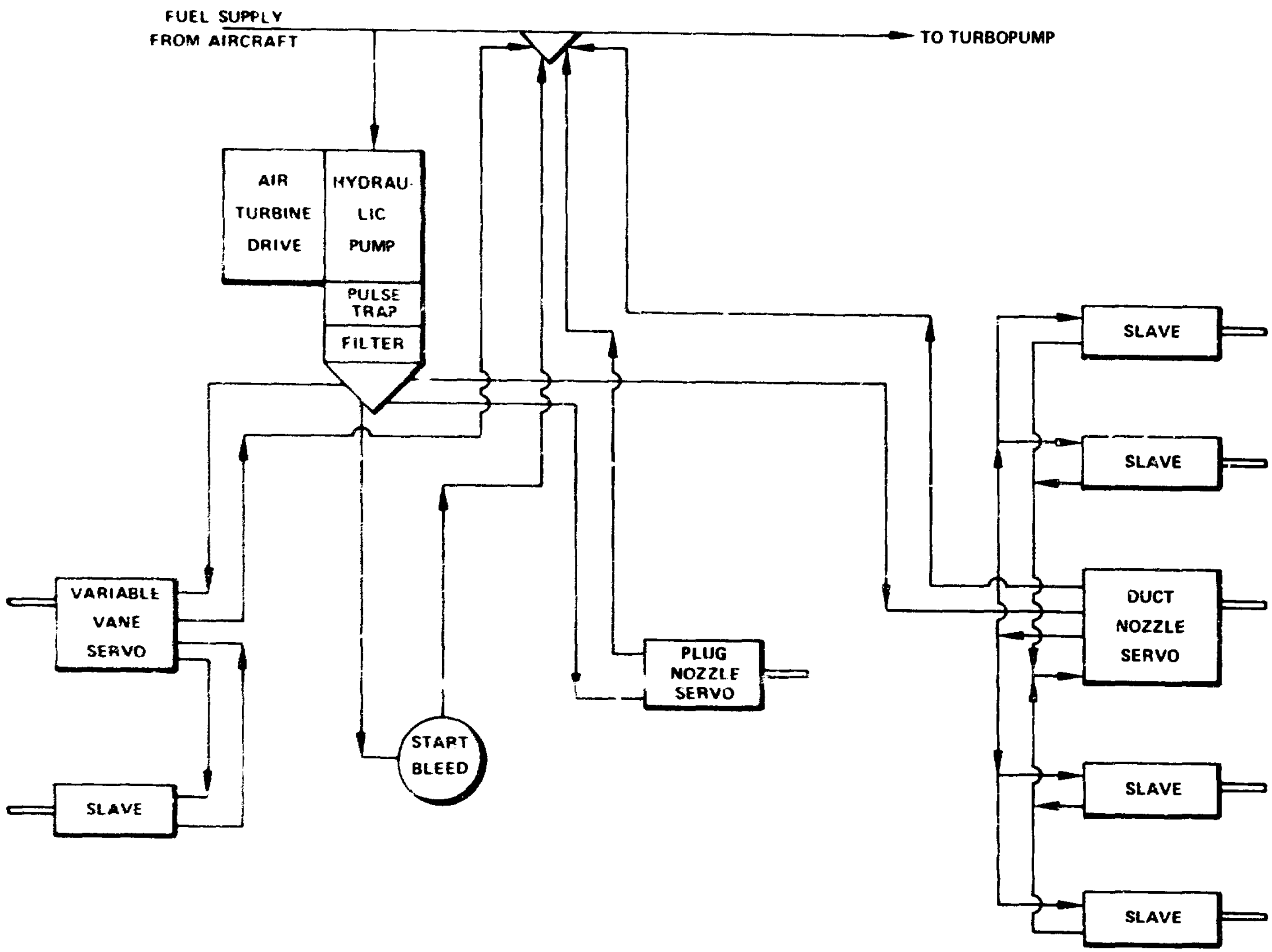


Figure 138. Fuel Hydraulic System for Alternative STRJ334B Design

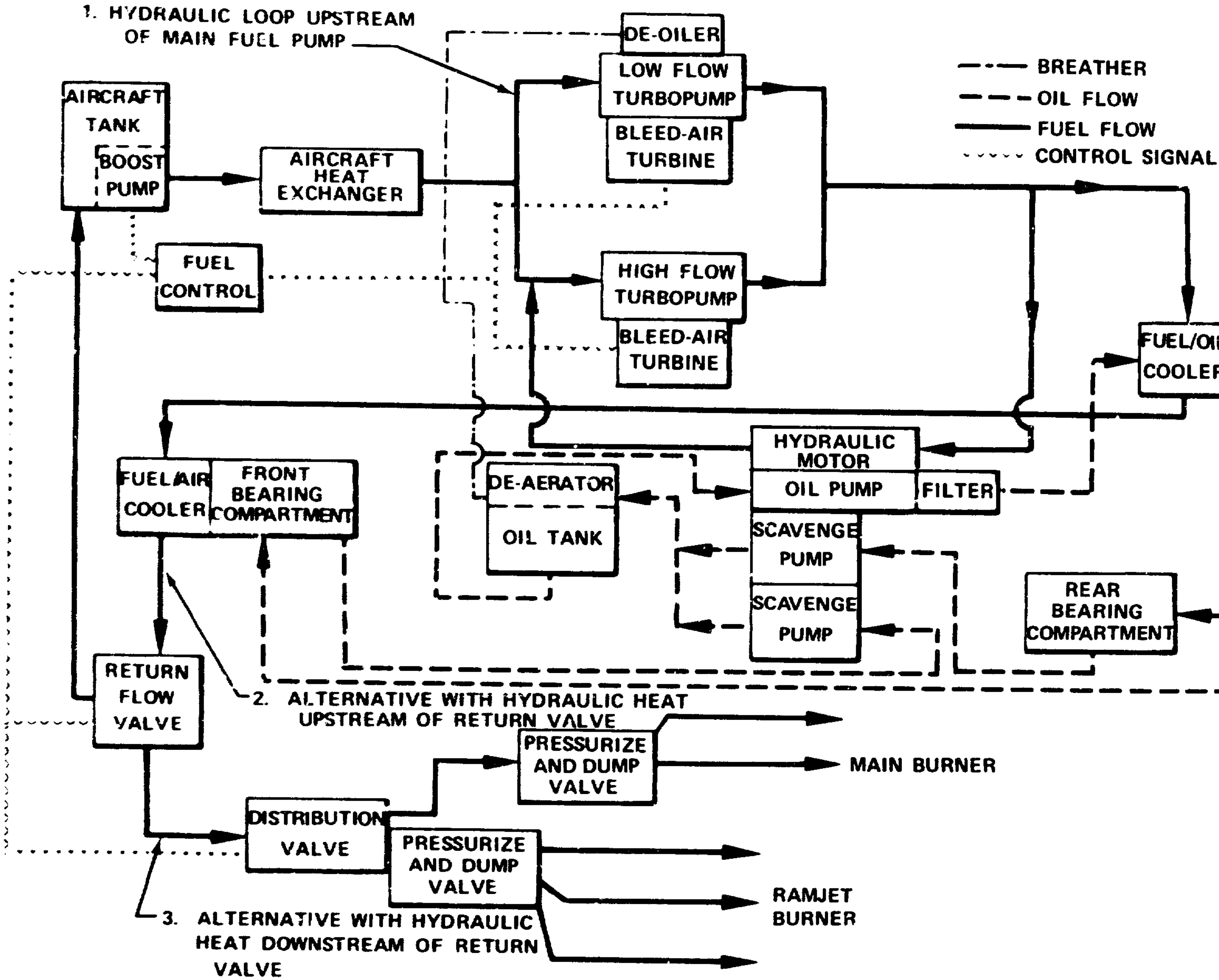


Figure 139. STRJ334B Engine Fuel and Lubrication System Hydraulic Alternates

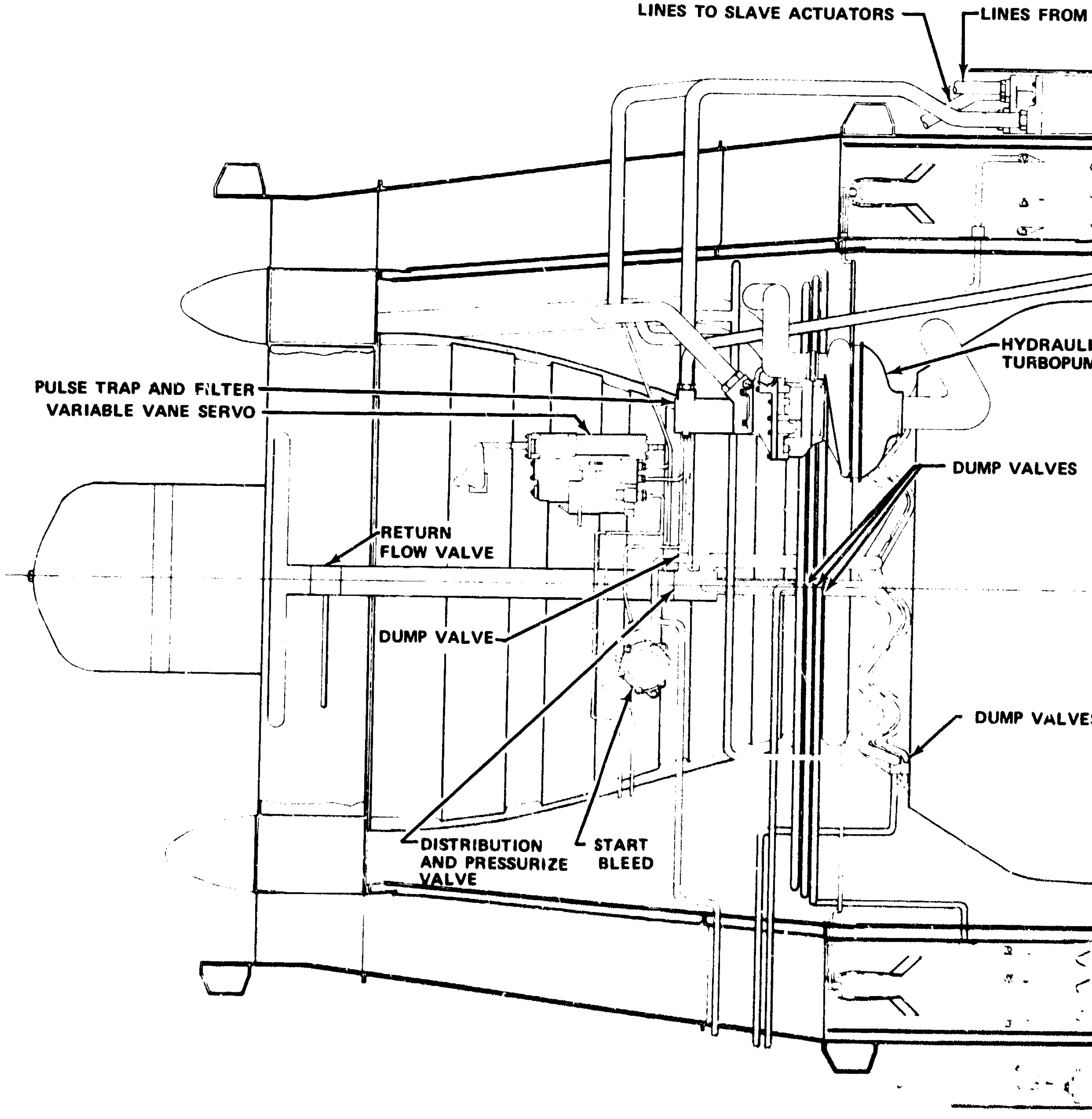

LINES TO SLAVE ACTUATORS
LINES FROM
HYDRAULI
TURBOPUM
PULSE TRAP AND FILTER
VARIABLE VANE SERVO
DUMP VALVES
RETURN
FLOW VALVE
DUMP VALVE
DUMP VALVES
DISTRIBUTION
AND PRESSURIZE
VALVE
START
BLEED

Figure 140.

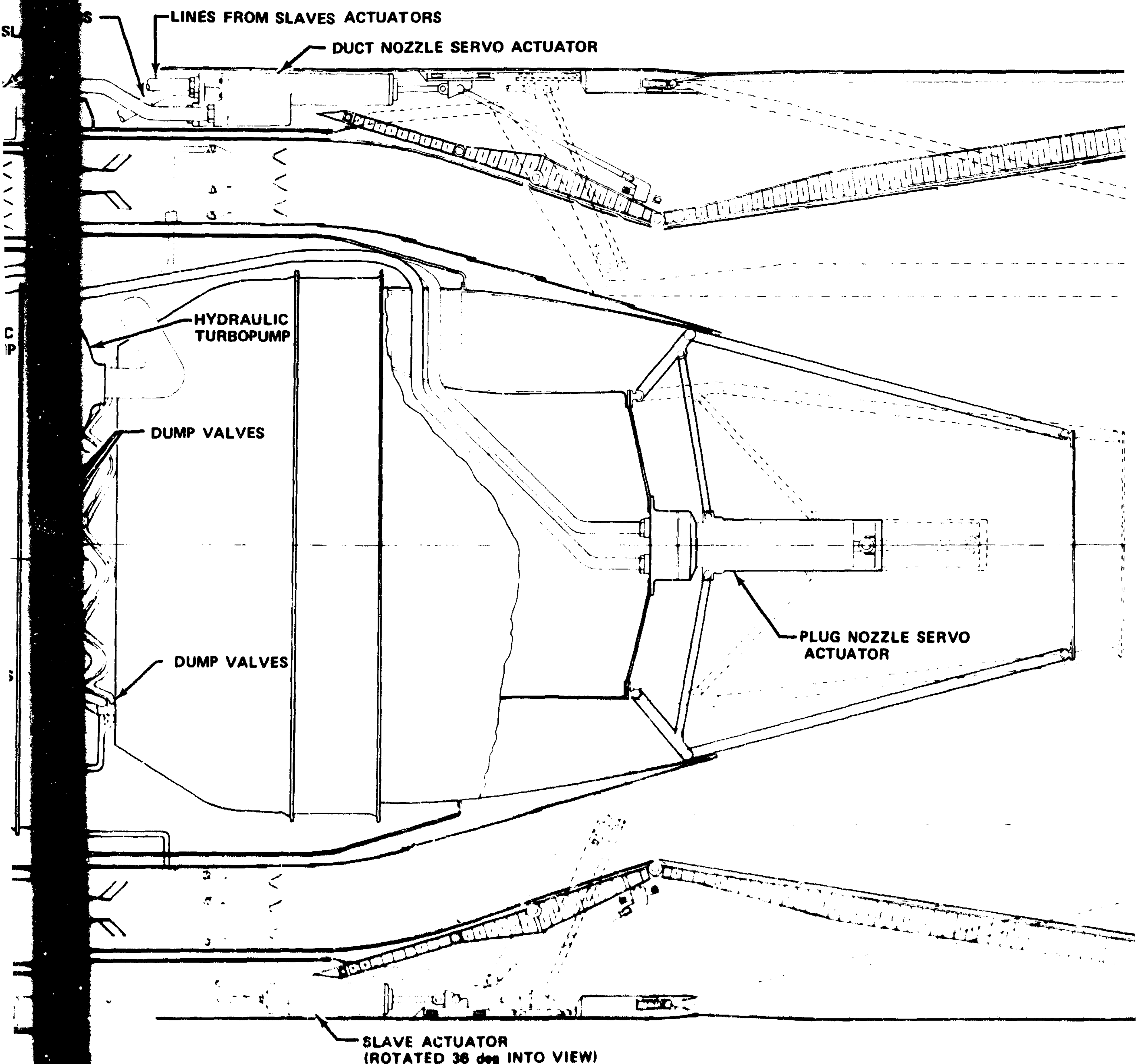
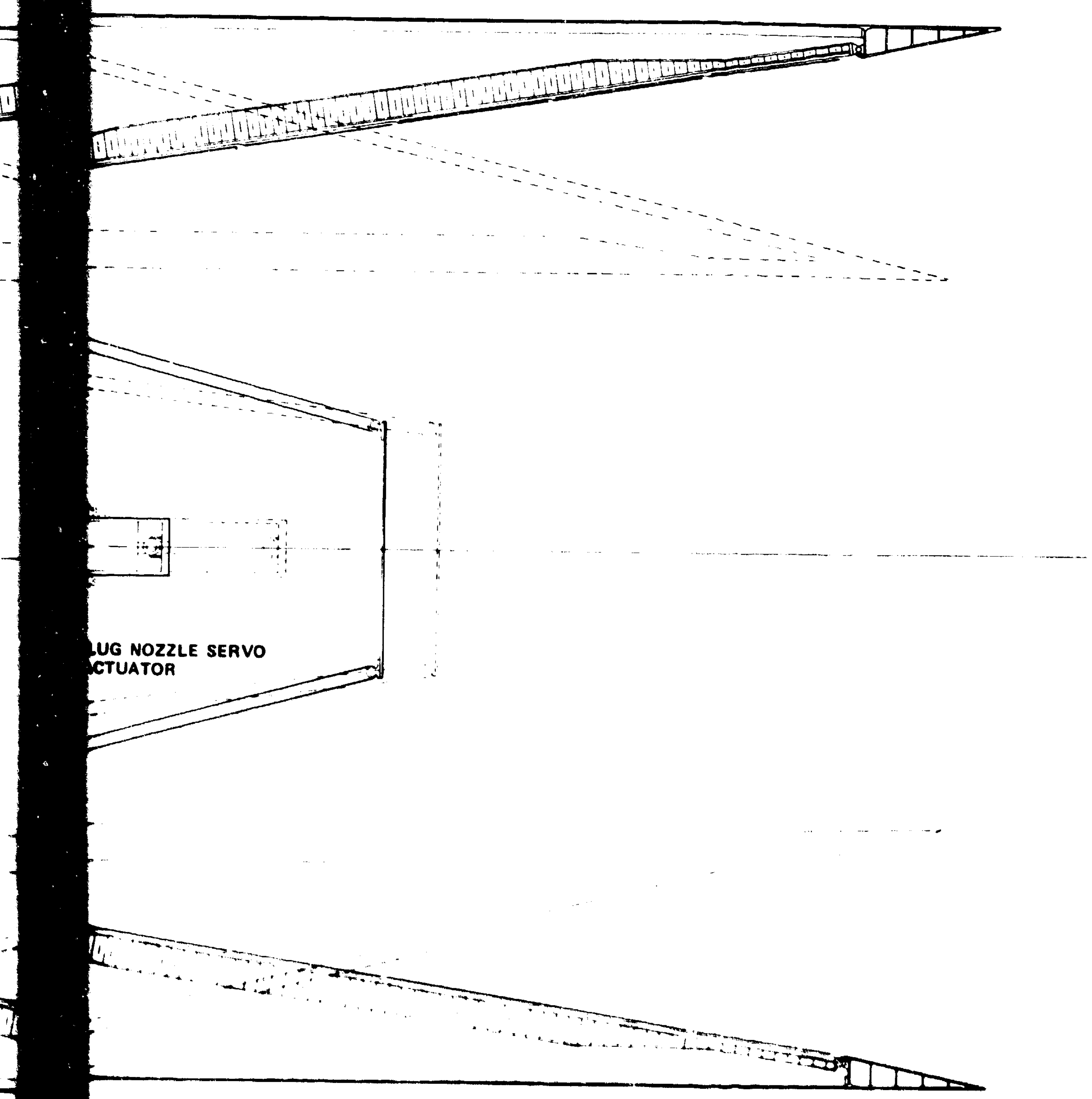


Figure 140. STRJ334B With Hydraulic Actuation System


LUG NOZZLE SERVO
CTUATOR

The new nozzle consists of a balance flap, a converging flap, and a diverging flap. The advantage of the balanced-beam design is that the duct pressure acting on the balance flap and that portion of the converging flap forward of the pivot provide a restoring force acting about the support pivot of the convergent flap. This restoring force acts as a counterbalance to resultant gas loads acting on the nozzle. This greatly reduces the required actuation force and attendant hydraulic heat loads. The forward end of the balance flap is connected to each adjacent flap with a clevis and spherical bearing, thereby forming a continuous hoop which supports that end of the flap.

Nozzle throat areas are varied by means of a bellcrank actuating system, similar to that on the JTF22. The system linkage forms a double hoop around the convergent flaps near the throat. As the bellcranks are unwound by the actuating rods, the diameter of the hoop is increased, the flaps are pushed apart, and the convergence angle is decreased, thus increasing throat area.

The divergent flaps are of a free-floating design, free to move in and out depending on the pressure forces acting on them. They are designed to seek the position, where the exit pressure is equal to the ambient pressure.

The balanced-beam nozzle requires a maximum actuation force of 50,000 lb. It is operated by one servo actuator and four slave actuators having a 2.17 in. piston diameter and 7.5 in. stroke; these have a 10,000-lb capacity, with a 3000-psi ΔP. The five duct nozzle actuators have a maximum total flow of 13,680 lb/hr. The required steady-state cooling flow is estimated to be 80.5 lb/hr per actuator, accomplished by piston cooling, which maintains a constant flow through the hydraulic system.

The plug nozzle has a maximum actuator force of 28,000 lb. It is operated by one servo actuator having a 3.63-in. diameter piston and 9-in. stroke. The maximum flow to operate the plug nozzle is 9006 lb/hr.

To obtain loads for the compressor variable vanes, a comparison was made with an advanced five-stage 12:1 compressor, currently under study. It was assumed that the STRJ334B would have a variable flap on the IGV and that the first three stages would have variable vanes. All four would be synchronized together and operated by one servo and one slave actuator. The total required actuator force is 1500 lb. The actuators will have a 2.00-in. stroke, and a 0.595-in. piston diameter. The maximum actuation flow is 268 lb/hr.

A start bleed arrangement, similar to the one on the JTF22, was assumed. The required actuator force is 1425 lb. This was supplied by one actuator with a 2.00-in. stroke and a 0.82-in. diameter piston. It had a maximum actuation flow of 182 lb/hr.

The hydraulic actuation system has an exposed area of 24.886 ft^2. This area, in addition to the heat generated by the hydraulic actuation system, results in a relatively large heat load.

c. Hydraulic System Heat Load Effects

The hydraulic system heat load due to pumping and environmental heating is added upstream of engine pumps for alternate No. 1 (figure 139) by circulating

engine fuel through the hydraulic system. Minimum flow to maintain pressure and cool the system is 5000 lb/hr. Major disadvantages of this approach are that main fuel pump net-positive-suction pressure is reduced by the fuel heating, and lubricant temperature is increased by higher fuel temperature into the fuel/oil cooler. Although the fuel temperature at the fuel nozzles could be increased, these disadvantages could be circumvented by alternates No. 2 and 3, which add the hydraulic heat load downstream of pumps and oil coolers through indirect exchange in a fuel/hydraulic fluid heat exchanger. Engine flow disturbances are avoided using this closed-loop hydraulic system with a heat exchanger to reject hydraulic system heat to the engine fuel system. Engine weight is estimated to be increased 50 lb to provide the heat exchanger system. Alternate No. 2 locates the hydraulic-fuel heat exchanger so that recirculation of fuel to the aircraft increases its fuel flow, thereby limiting maximum engine fuel temperatures. Alternate No. 3 locates the hydraulic-fuel heat exchanger to add hydraulic heat only to fuel consumed by the engine. This avoids addition of hydraulic heat to the aircraft by recirculation, but provides no supplemental cooling to limit hydraulic system or engine fuel temperature if engine fuel consumption is too low for adequate cooling.

The heat generated in pumping hydraulic fluid remains relatively constant to sustain flow at 5000 lb/hr and 3000 psia; the peak flow of 25,000 lb/hr is needed only for short bursts during maximum actuation rates, and the resulting transient heat load is absorbed by the system heat capacity. The total of pump and environmental heating for the hydraulic system is estimated to reach a maximum of 6900 Btu/min at maximum flight speed for alternate No. 1. This adds a heat load to each engine system that is approximately the same as the estimated aircraft heat load that must be absorbed by the fuel flow to each engine (1/2 total aircraft heat load). This comparison shows the desirability of developing improved actuation systems that can operate at higher temperatures to reduce this load and ultimately that might eliminate fuel cooling altogether by using the uncooled pneumatic system proposed in the baseline system.

It has not been the intent to recalculate fuel and lubricant temperatures with this hydraulic actuation modification to the baseline system design for all previous operating conditions. Because the hydraulic load is similar to the estimated aircraft heat load, the previously calculated effects for a throttle-chop at maximum cruise Mach number would be essentially unchanged if the aircraft thermal management system were changed so that the aircraft heat load is absorbed by fuel in the aircraft tanks during these transient conditions. The primary effect would be an increase in tank temperature for each maneuver of an amount inversely proportional to the quantity of remaining fuel. The number of such maneuvers and the required fuel reserves could be limited consistent with the fuel thermal degradation tolerance and the final fuel tank temperature. For the baseline mission, there is only a single descent maneuver, and heat capacity of the fuel is not exceeded. The effects on the baseline mission fuel and lubricant temperature profiles have been calculated for addition of hydraulic heat loads at the three alternate locations.

Fuel temperature profiles for the mission are shown in figure 141 for the open-loop hydraulic system (alternate No. 1 to the baseline fuel and lubrication system). Maximum temperature just prior to descent of 375°F compares to 335°F for the baseline design. The peak temperature for the descent transient at throttle reduction is increased to 730°F, compared to 515°F for the baseline, on the basis of 1000 lb/hr recirculation. Figure 142 compares fuel system

component temperature profiles with and without the alternate No. 1 hydraulic system for the initial descent operating point. The aircraft heat load is absorbed by onboard fuel for this low flow transient, as originally programed for the baseline thermal management system. Because of the low engine fuel flow at descent with only 1000 lb/hr of recirculated flow (upper curve), a fuel temperature rise of approximately 300°F is caused by the hydraulic system (compared to 40°F for cruise). Temperatures at the pump inlet (450°F) and airframe return from fuel/air cooler discharge (640°F) would be problems, assuming JP-7 might be usable to 730°F for the transient and low residence time conditions at fuel nozzles. However, because the condition is transient, the system heat capacity attenuates these peaks, and recirculation of flow can be used to reduce temperatures. The second highest temperature profile shows that a fuel recirculation rate of 2050 lb/hr could reduce the maximum fuel temperature to less than 600°F, compatible with use of JP-7 fuel. Engine pump inlet temperature is reduced to 375°F, corresponding to an acceptable JP-7 vapor pressure of 10 psia. Recirculation temperature is still higher than desirable at nearly 500°F at the fuel/air cooler discharge and either higher recirculation rate or recirculation from a lower temperature component location would be considered in a final design. Allowable maximum/airframe/engine interface temperature would be reduced by the 40°F increase that the hydraulic system causes during steady-state cruise conditions.

Mission fuel temperature profiles for the ramjet fuel nozzle temperature are shown in figure 143 for the baseline design and the three hydraulic actuation system alternates. Maximum fuel temperatures at cruise back power setting are approximately 40, 52, and 60°F higher than the baseline for alternates No. 1, 2, and 3, respectively. The trend is for somewhat higher maximum fuel temperature the further downstream that the hydraulic heat load is added, since this reduces the temperature difference between fuel and ambient in an increasing fraction of the exposed area of the fuel system. Transient descent temperatures are shown for 1000 lb/hr recirculation and could be reduced as shown previously in figure 142 by higher recirculation rates.

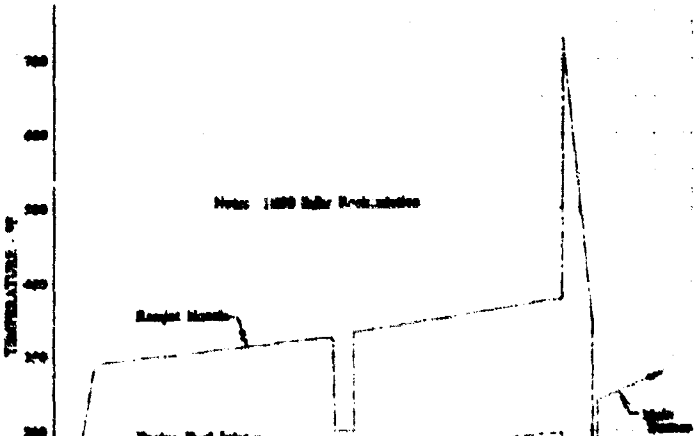


Figure 141. STRJ334B Mission Fuel Temperatures Assuming Hydraulic Loop at Main Fuel Pump Inlet

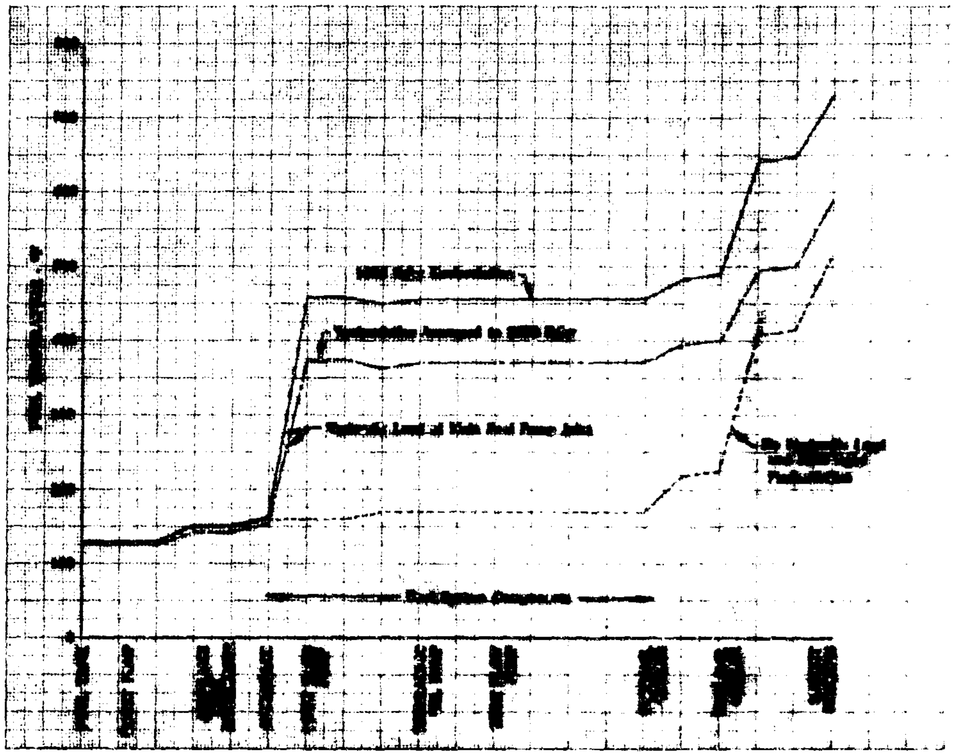


Figure 142. STRJ334B Fuel Temperature Profile at Initial Descent

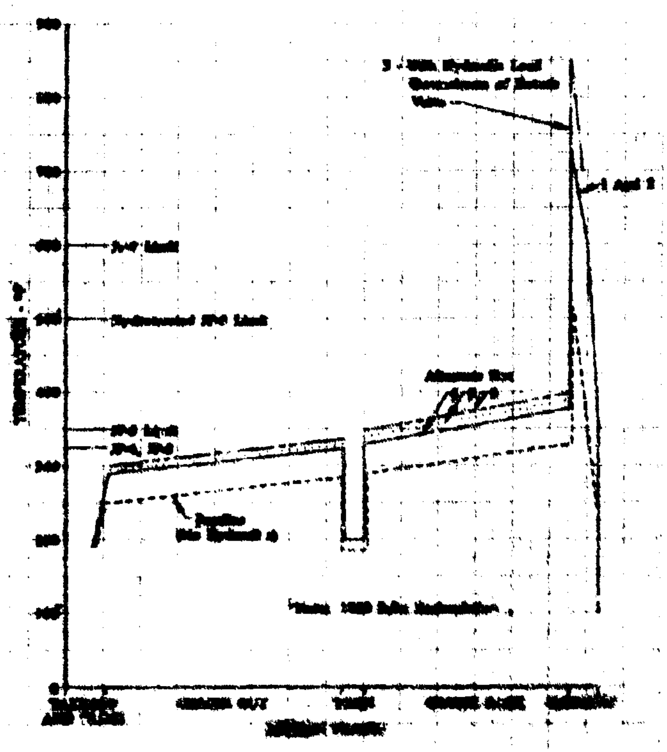


Figure 143. STRJ334B Mission Ramjet Nozzle Fuel Temperatures

Lubricant temperatures resulting from the preceding fuel temperatures using hydraulic actuation are shown in figure 144. The lower temperature profile represents the baseline design or alternates No. 2 and 3 that add hydraulic heat loads downstream of the fuel/oil cooler. Lubricant temperatures are the highest during climb for this profile; however, the upper curves, representing addition of hydraulic heat loads upstream of the oil cooler, show highest lubricant temperatures at the descent transient. This transient is shown to exceed the 500°F limit of hypothetical ester for 1000 lb/hr recirculation of fuel. The 2050 lb/hr recirculation rate needed to limit maximum fuel temperature to 600°F is also shown to reduce lubricant temperature to a level consistent with use of MIL-L-27502.

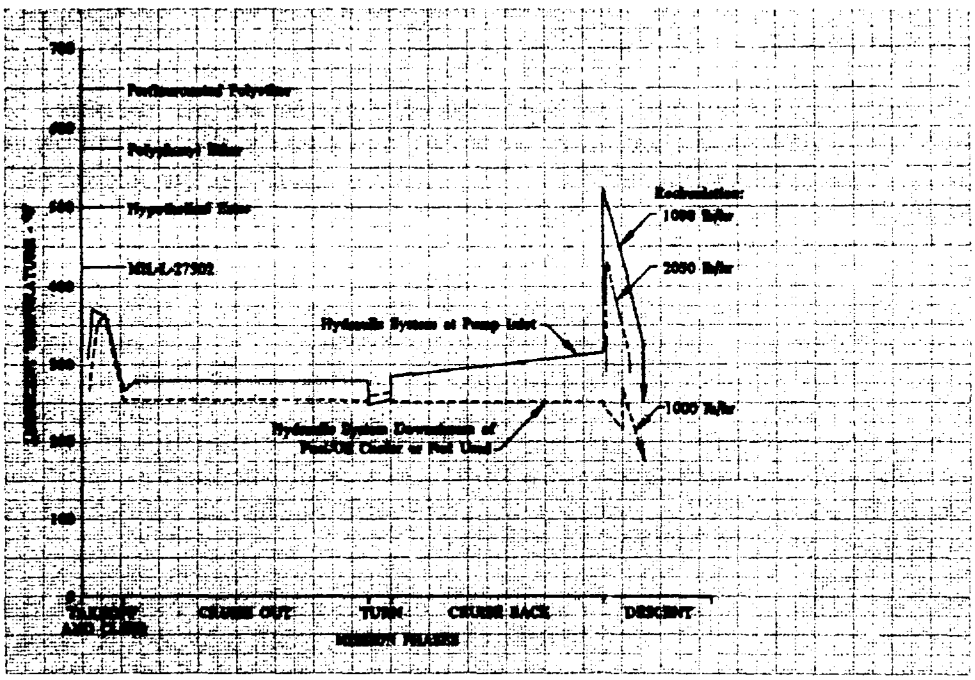


Figure 144. STRJ334B Lubricant Maximum Temperatures During Mission for Alternate Designs

As concluded in previous reports evaluating transient flight conditions, fuel recirculation provides a solution to limit temperatures to levels consistent with selected fuels and lubricants. Fuel flow is more than adequate to provide cooling during steady-state cruise conditions, but supplementary cooling is needed for transient operation of the STRJ334B turboramjet.

The most serious compromise to system capabilities would be the loss in flexibility to operate at conditions beyond those included in the baseline mission. The more frequent and extensive need for fuel recirculation would cause a more rapid increase in fuel tank temperature that could result in fuel overtemperature near the end of a flight unless maneuvers requiring low fuel flow were curtailed. Subsonic loiter might require addition of an air/fuel or air/oil cooler. The maximum allowable aircraft tank temperature or interface temperature would be decreased 40 to 50°F for the same limiting burner nozzle fuel temperature. It can be concluded that development of actuation systems such as postulated for the baseline design would offer many benefits over today's hydraulic system technology, although it is not essential for basic feasibility of the STRJ334B

operation with JP-7 type fuel. The following paragraphs suggest feasibility for development of a pneumatic system.

d. Alternate Pneumatic Actuation Systems

The STRJ334B baseline engine has a pneumatic actuation system (figure 86) similar to the F100 engine nozzle actuation system. The F100-PW-100 system is designed for a maximum temperature environment of 500°F. To be able to use the F100 system in a 1200°F+ environment, there would have to be sizable advances in technology.

The STRJ334B system consists of an air regulator, a servo-controlled, air turbine, and five ball screw actuators, coupled and synchronized by flexible power transmission shafts.

The air regulator supplies high pressure air to the air turbine. The air turbine directly drives the primary actuator and drives the secondary actuators through the rotating flexible shafts. The flexible shafts form a closed loop through all five actuators. The actuator jackscrew translates a ball nut linearly to reposition the exhaust nozzle.

With this baseline pneumatic system, the core nozzle is actuated by one ballscrew, driven by a servo controlled air turbine. The variable vanes are driven by a servo-controlled air turbine, which drives two ball screws through a flexible shaft. For this baseline system, the only fuel cooling assumed was that of the servo controls. Each servo required three fuel lines: a supply line, a return line and an overboard dump line. The total exposed area of the system is shown in table XXI and a weight comparison is shown in table XXII compared to the hydraulic system areas and weights.

The question is whether this system can be made to operate at the high temperatures. Although it is felt that materials technology would be adequate, there would be problems in lubricating the moving parts. Parts with relatively slow movement, such as ball screws, rod end bearings, etc., could be made using high temperature materials and hard facing techniques. Examples of these, which could be tested, are WASPALOY® with Borcote, Borofuse or Tribaloy. Another area worthy of investigation and testing is the use of ceramic parts such as K-RAMIC. The use of air bearings for the high speed parts could be considered.

The pneumatic actuation system would require testing and further investigation to determine if components, such as air turbines, flexible shafts, etc., could be made to run uncooled and either run dry or develop a means of lubricating them at the high temperature.

There are several actuation schemes for the duct nozzle that deserve further investigation that would require little or no cooling. These would require some advancement in high temperature component technology, but many of the problems can be eliminated by designing such that problem items are avoided. For example, it was thought that a mechanical system would not be feasible because of the problems associated with a flexible shaft drive. However, a system could be designed using a rotating ring such as shown in figure 145. The ring would perform the dual purpose of actuating the flaps and synchronizing them together. It could be supported by rollers or by links. In either case, this could be done today using high temperature materials and hard facing techniques previously described.

The ring could be driven by an air turbine driving through a gear reduction and ball screw at two locations. The air turbine and gear reduction at this time would need to be cooled, but the cooling required would be a small fraction of that of the hydraulic actuation system. High temperature air turbines, perhaps with air bearings, and gear reductions that could operate in a 1200°F+ environment are recommended as areas for further study to advance present technology.

A scheme that would eliminate the need for both a power source and drive is shown in figure 146. This design uses the high pressure duct air directly to actuate the nozzle, thus eliminating the need for air turbines and drives. The nozzle throat area is controlled by a servo-controlled air valve.

Table XXI. Exposed Area Comparison Between Hydraulic and Pneumatic Actuation Systems

Actuation Systems	Exposed Area, ft^2
Existing Engine	
Fuel System	32
Oil System	7.4
Addition for Hydraulic System	
Fuel Lines	15
Components	10
Total	25
Addition for Pneumatic System	
Fuel Lines	2.8
Components	6.5
Total	9.3
Total Exposed Area for Hydraulic System	
Existing Engine	32
Hydraulic System	25
Total	57
Total Exposed Area for Pneumatic System	
Existing Engine	32
Pneumatic System	9.3
Total	41.3

Table XXII. Weight Comparison for Exhaust Nozzle Actuation Systems

Exhaust Nozzle Systems	Weight, lb
System 1 - Hydraulic System (Alternate No. 1)	
Linear Actuators	27
Unison Ring	48
Hydraulic Lines	23
Pulse Dampers and Filter	4
Feedback System	5
Turbopump	29
Actuator Control	21
Total	157
System 2 - Air Turbine, Ball Screw, Flex-Cable	
Ball Screws	32
Synchronizing and Drive Cables	18
Air Turbine	17
Air Lines	7
Feedback and Control System	13
Total	87
System 3 - Air Turbine, Ball Screw Rotating Synchronizing Ring	
Ball Screws	32
Rotating Synchronizing Ring	48
Air Turbine	17
Air Lines	7
Feedback and Control System	13
Total	117
System 4 - Duct Pressure Actuated Flap	
Feedback and Control System	14
Additional Flaps and Seals	104
Air Valves	10
Total	128

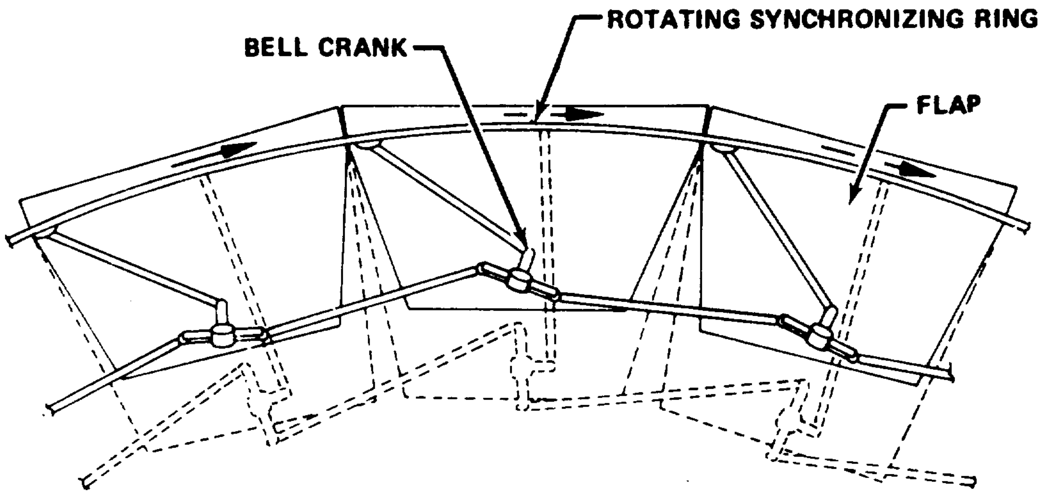


Figure 145. Noncooled Synchronizing Mechanism for Pneumatic-Actuated Exhaust Nozzle

As shown in figure 146, a pressure cavity is formed using conventional flaps and seals. Since the pressure flaps have approximately twice the area as the converging flap, the flaps would be pressure balanced with a pressure in the cavity of approximately 1/2 the nozzle entrance pressure. Theoretically, the air valve can vary the cavity pressure from nozzle entrance pressure to ambient, which is almost negligible. Allowing the pressure in the cavity to approach that of the duct would force the flaps to close. To relieve the pressure would let the flaps move out, opening the nozzle. The flaps could be synchronized by a mechanical linkage such as the rotating synchronizing ring shown in figure 145. The servo control would have to be cooled but the heat load would be small. This system is shown in the weight comparison in table XXII. The weight of the additional flaps would probably be compensated for by lighter structure since the system is inherently pressure balanced.

To summarize, the hydraulic system would work, but would place a large heat load on the fuel. The pneumatic system would have a small heat load, but would require further study and testing to determine if it could be made to work at the high temperature. Areas in which effort is needed to advance present technology are high temperature lubricants, high temperature controls, air turbines, and drives. A duct pressure-actuated nozzle design is proposed as an alternative, which eliminates the air turbines and drives. It would require further study and testing to determine its feasibility.

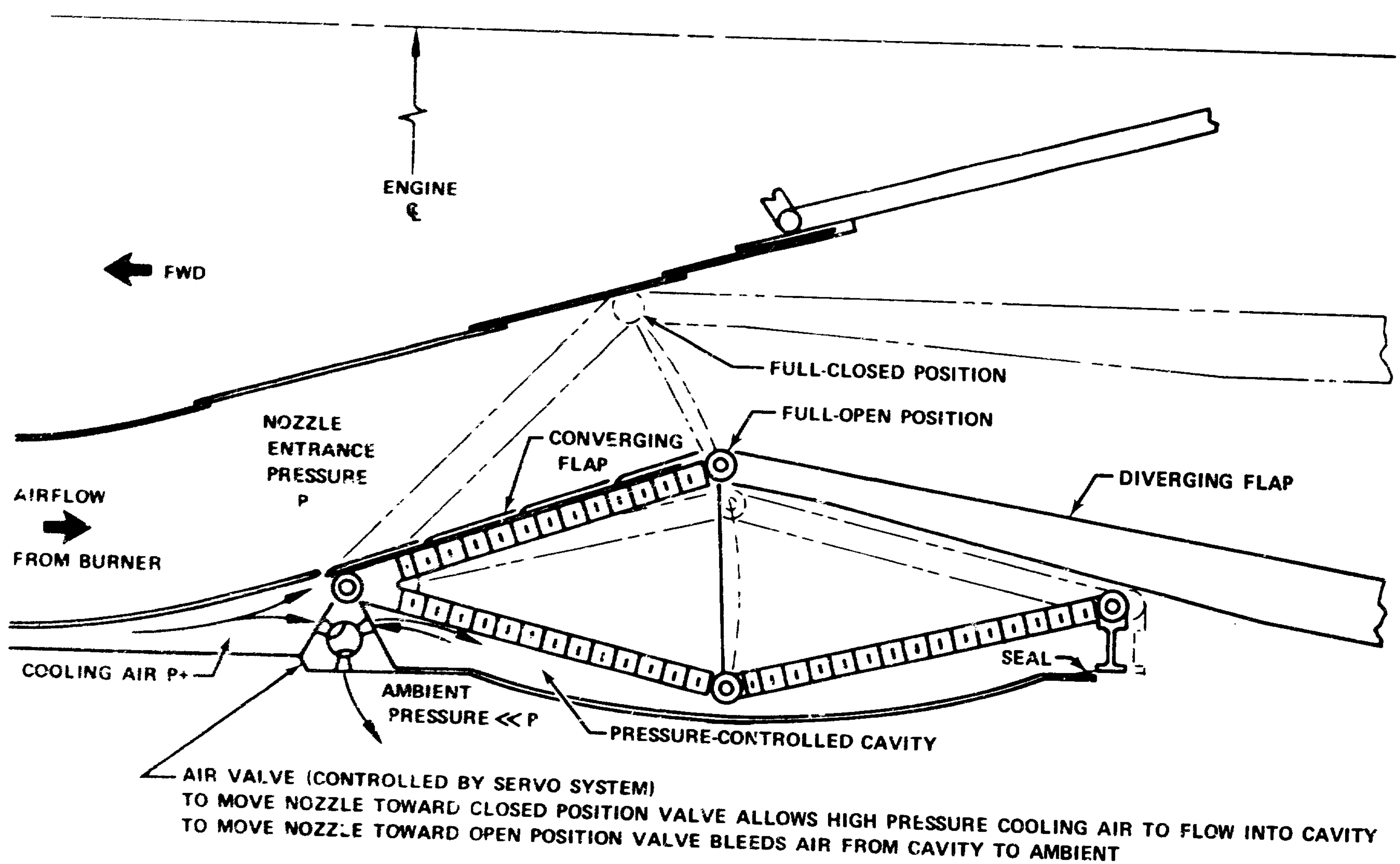


Figure 146. Nozzle Flap Concept Eliminating Need for Hydraulic or Pneumatic Actuators

6. STRJ334B Supplemental Fuel Cooling

The heat sink that was potentially available for the STRJ334B turboramjet utilization during the mission is shown in figure 147. The variation during the mission was as great as previously shown for the STJ346A. For this reason, two Btu/min scales were used to improve reading capability. The percentage of the total potential heat sink remaining, in the consumed fuel, for utilization by supplementary STRJ334B systems is shown in figure 148. Only 20% was available during descent using JP-7 fuel, but at all other flight conditions more than 70% was available for supplementary cooling. The variation in available rates of heat sink, shown for both engines by the previous figures, indicated that consideration be given to mission phases and engine operating requirements in the selection of supplementary systems. One example was the correspondence in time of supplementary cooling needs with available heat sink to identify concepts that would best enhance performance of the mission. If systems were found that showed significant benefits for the baseline mission, it would still be necessary to ensure that the engine flight envelope and maneuver capabilities were not impaired for alternate missions.

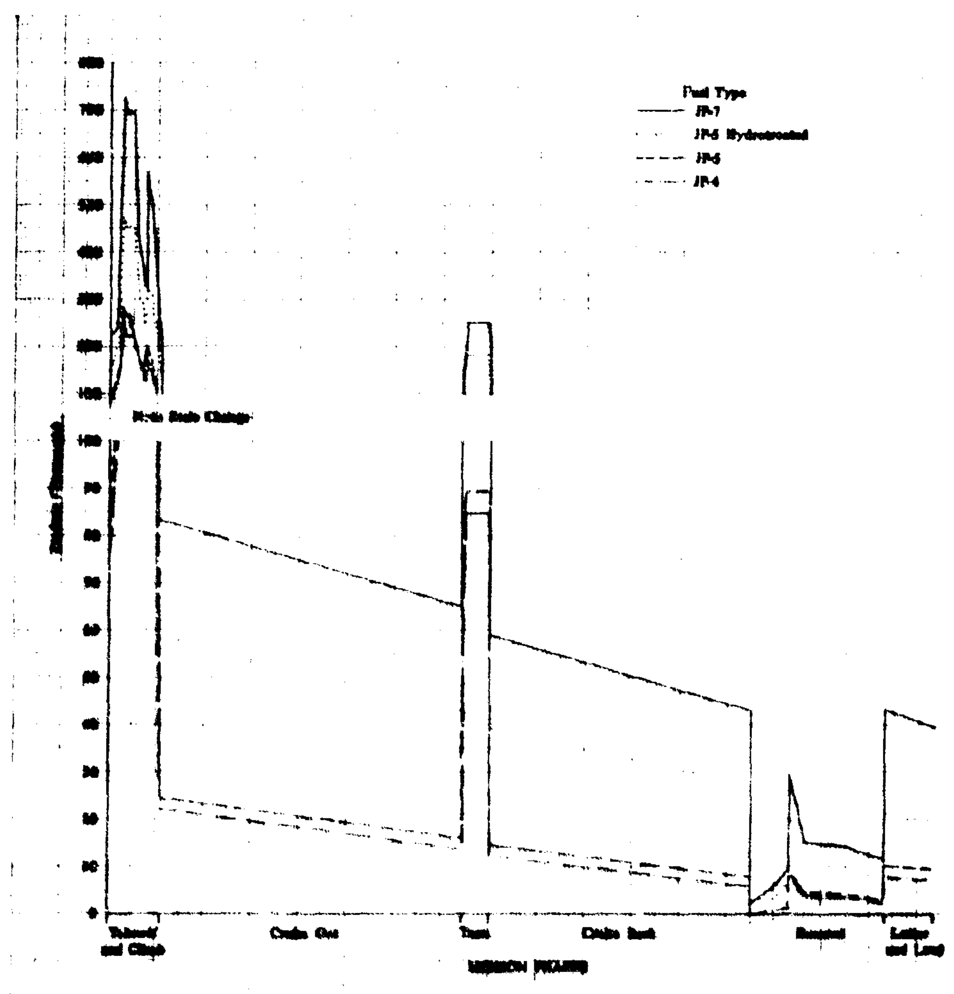


Figure 147. Potential Heat Sink Available for STRJ334B Utilization During the Mission

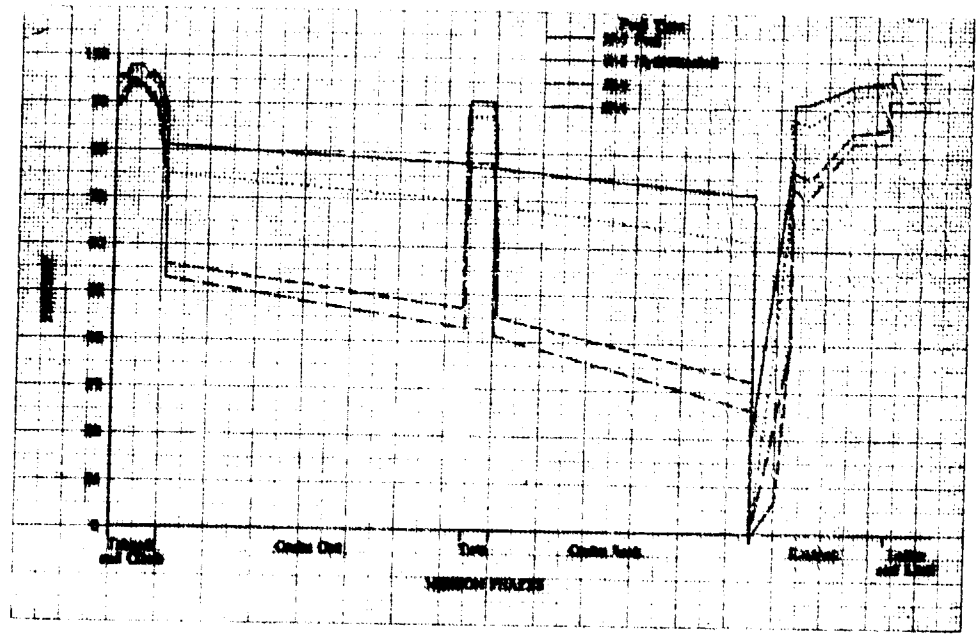


Figure 148. Percentage of the Potential Heat Sink Remaining in the Consumed Fuel for STRJ334B Utilization During the Mission

Based on the baseline mission, steady-state flight conditions, and use of JP-7 fuel to a maximum fuel temperature of 600°F, the unused fuel heat sink capacity was considered for additional fuel cooling for the aircraft, direct fuel cooling of engine structure, and fuel cooling of engine cooling air. A survey of aircraft designers indicated that removal of tank insulation to reduce aircraft weight was not practical because aircraft structure required insulation at the high Mach flight speeds of the STRJ334B, that environmental cooling systems required the lowest possible fuel temperatures (not greater heat sink) to minimize their weight, and that no other possibilities were envisioned for use of the additional fuel heat sink. Direct fuel cooling of the engine structure did not appear promising because of (1) negative results for similar evaluation of the STJ346A engine, and (2) the large temperature difference (between allowable fuel temperature and gas temperatures) across thin metal sections would have resulted in high thermal stresses, fuel coking, and fuel leaks. It was concluded that emphasis be on the evaluation of fuel cooling of engine cooling air for a representative concept, and if this were promising, alternates could be considered. Accordingly, heat exchangers were sized for fuel cooling of turbine and ramjet cooling air. The sizes were based on the minimum available excess fuel heat sink so that fuel temperature limits were not exceeded at any steady-state flight conditions.

An installation design was prepared for the heat exchangers, figure 149, to evaluate mechanical feasibility and to provide a basis for weight estimates needed in conjunction with estimates for improved engine performance to evaluate potential mission benefits. Although the weight is greater for the STRJ334B core engine cooling system due to higher turbine operating temperature, the arrangement for turbine vane and blade cooling is similar to that for the STJ346A shown in figure 70, Section III, paragraph E. Estimated weight for the turbine cooling system for the STRJ334B is 150 lb and for the ramjet cooling system, 75 lb. The turbine

cooling and ramjet cooling systems are independent. Turbine cooling air is bled from compressor discharge, passed through an annular, turbine-cooling, fuel-air heat exchanger and used to cool turbine vanes, rub strips, and rotating parts (disks and blades). Fuel from the fuel distribution valve flows to the turbine cooling valve for distribution to the turbine cooling fuel/air heat exchanger, from which it is distributed to a zoning valve controlling distribution to the two-zone turbojet fuel nozzles. The turbojet is shut down when supplementary ramjet cooling is used to advantage; fuel flow is then directed from the fuel distribution valve to the cylindrical-shaped, ramjet fuel/air heat exchanger, and to the ramjet combustor fuel nozzles. Dump valves are provided to drain fuel from heat exchangers when not in use to avoid coking. Cooling air for the ramjet combustor and exhaust nozzle is collected in an annular duct and plenum at the ID, cooled in the ramjet fuel/air heat exchanger, and redistributed around the ramjet ID into an annular plenum in front of the combustor. Part of this air is directed to the ID cooling liner of the ram combustor; the rest is directed through struts in front of the ram combustor to the OD cooling liner. Air shutoff and bypass valves in the system permit heat exchanger bypassing when fuel would otherwise be overheated at low power settings (supplementary cooling is not needed at these conditions).

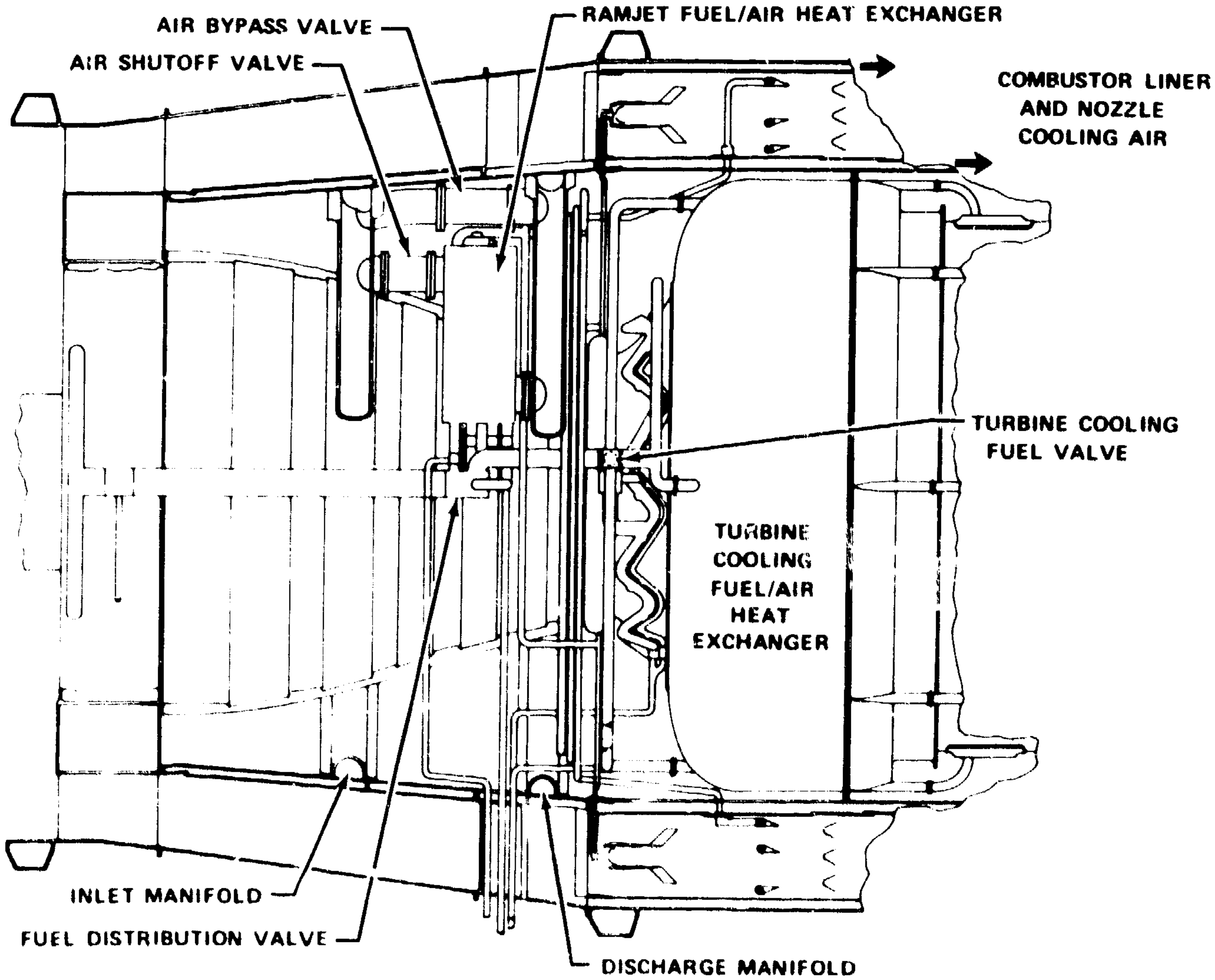


Figure 149. STRJ334B Turbine and Ram Combustor Supplementary Cooling Systems

The cooling air flowrate for the turbine vanes and blades of the STRJ334B varies to provide adequate cooling for various operating turbine temperatures. After takeoff and for the major portion of the acceleration phase of the mission, the use of fuel cooling of turbine cooling air permits a reduction of cooling air temperature an average of 180°F and an allowable reduction in cooling air flow of 4% of total engine airflow. Analysis of ramjet cooling air requirements and sizing of the cooling system for the minimum available excess fuel heat sink indicated that the cooling air temperature could be reduced approximately 300°F at the design point. This reduces required cooling airflow by 1.2% of total ramjet airflow. The changed engine characteristics of reduced cooling flow and 225 lb increase in cooling systems weight were used to compute their effect on performance of the mission.

The potential benefits of fuel cooling were evaluated in the computer program developed in FRDC APSI studies under Contract F33657-69-C-0270 and used in the original sizing of engines and aircraft for the subject contract. The minimum aircraft gross takeoff weight (GTOW) was found to be 0.1% less using the supplementary cooling system. However, the turn g-loading capability was reduced at this minimum aircraft weight. Restoring the original turn capability was calculated to require an increased TOGW. Therefore, it was concluded that the net benefit in TOGW was marginal or nonexistent for fuel cooling of turbojet and ramjet cooling air. Because of the potential disadvantages in cost, reliability, maintainability, safety, and operating flexibility for alternate missions, it was concluded that much greater fuel cooling capability was necessary to show sufficient performance advantage to warrant use of this type of system.

7. Alternate Fuel and Lubrication Concepts for STRJ334B

a. Fuel/Oil Cooler

An integral fuel/oil cooler and oil tank system was initially considered to minimize the bulk oil storage temperature. A fin-tube heat exchanger was selected for maximum oil side surface area to compensate for low oil heat transfer coefficients. The oil cooler location on the suction side of the pump did not permit the high pressure losses needed to attain high oil velocity and corresponding high heat transfer effectiveness. A comparison of the low heat transfer capability of a fin-tube heat exchanger in the oil tank with the higher heat transfer capability of the tube-shell heat exchanger downstream of the oil pump is shown in figure 150. The initially estimated heat loads for the bearing compartments are shown for the various phases of the mission in figure 151. At the start of cruise, the oil system must remove an estimated 750 Btu/min without considering other heat sources. At an engine fuel flow of 20,000 lb/hr, the fin-tube heat exchanger will only transfer 550 Btu/min, with a differential of 100°F between fuel and oil inlet temperature. The tube-shell heat exchanger downstream of oil pumps has five times the heat transfer capability of the fin-tube heat exchanger at this point in the mission. As the cruise continues and the fuel flow decreases, this deficiency of the fin-tube heat exchanger (integral with the oil tank) and the advantage of the tube-shell cooler increase.

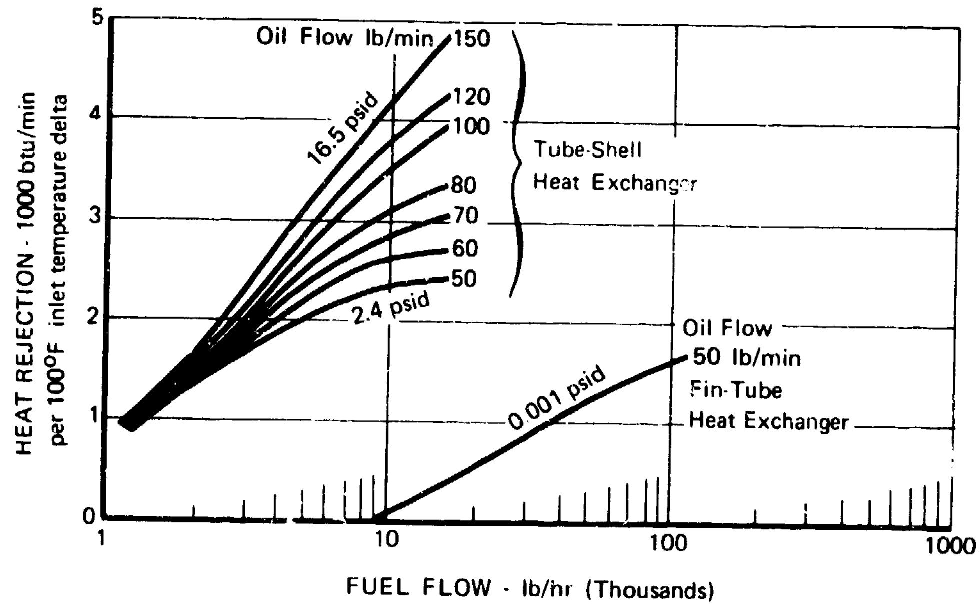


Figure 150. High Pressure Tube-Shell Oil Cooler Performance Exceeds Integral Oil Tank Fin-Tube Cooler

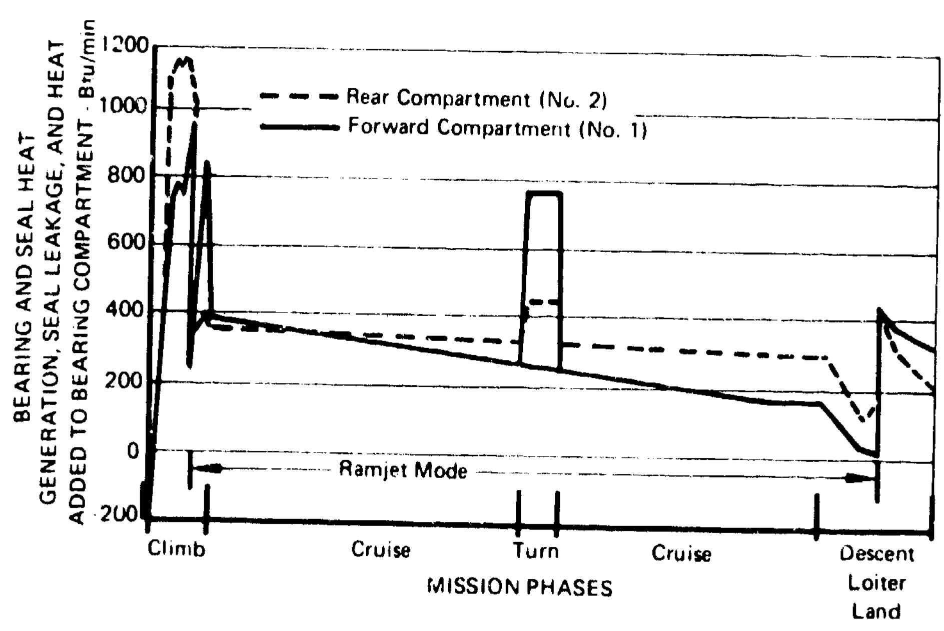


Figure 151. Turbojet Bearing Compartment Heat Loads Remain High During Ramjet Operation

b. Lubricant Pump Drive

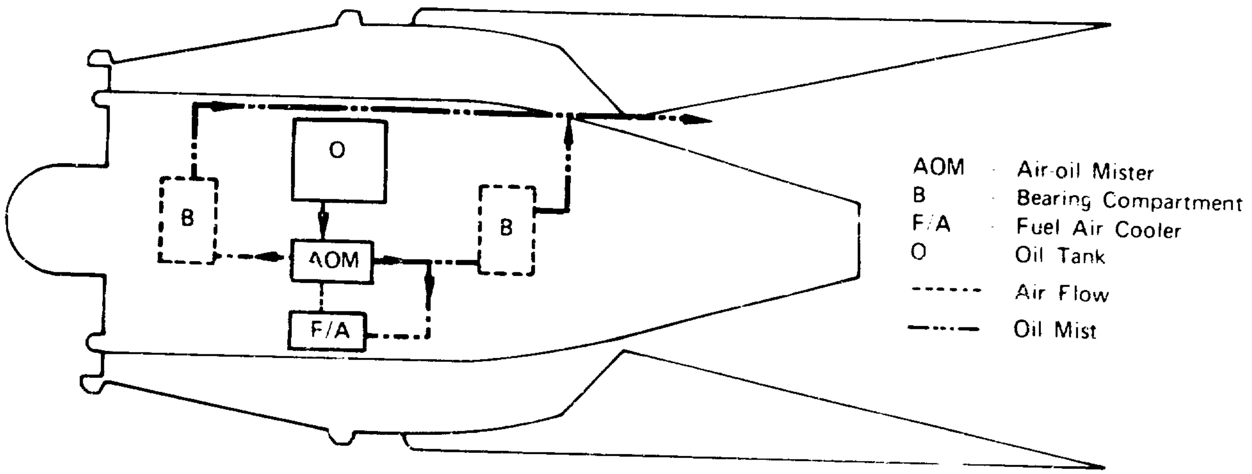
The STRJ334B turbojet core engine bearing compartment heat loads and oil cooling requirements remain at a significantly high level when the core is shut down and the engine operation is on ramjet-only as shown in figure 151. Increased environmental heating during the ramjet cruise mode is the cause. While operating on the ramjet, the turbojet core engine should be motored at about 100 rpm to maintain bearing compartment oil flow in passages requiring centrifugal pressure. At this low speed, rotor-driven oil pressure and scavenge pumps do not circulate the estimated oil cooling flow requirement of 50 lb/min. To windmill the engine at higher speed would add an unacceptable penalty on the aircraft inlet size and weight. For these reasons the oil pumps were removed from the engine bearing compartments and combined in a single component. A hydraulic motor, powered by the available fuel system flow, was selected to drive the oil pumps at any desired speed during all operating modes of the engine. All components are self-lubricating.

c. Oil-Mist Lubrication

A once-through oil-mist alternative is shown in figure 152. In this concept, air precooled with fuel provides cooling of bearings and the lubricant is used only to provide a lubricating film. Because the lubricant is not required to transport heat from bearings, flowrates are low, and lubricant can be discharged after use. This provides the potential reliability of a static system, but was judged to be unattractive for the high bearing compartment temperatures determined for the STRJ334B. The cooling of ram air to temperatures below the autoignition temperature of lubricants would require a relatively large heat exchanger and/or increased autoignition temperature capability of lubricant.

d. Simplified Fuel Control System

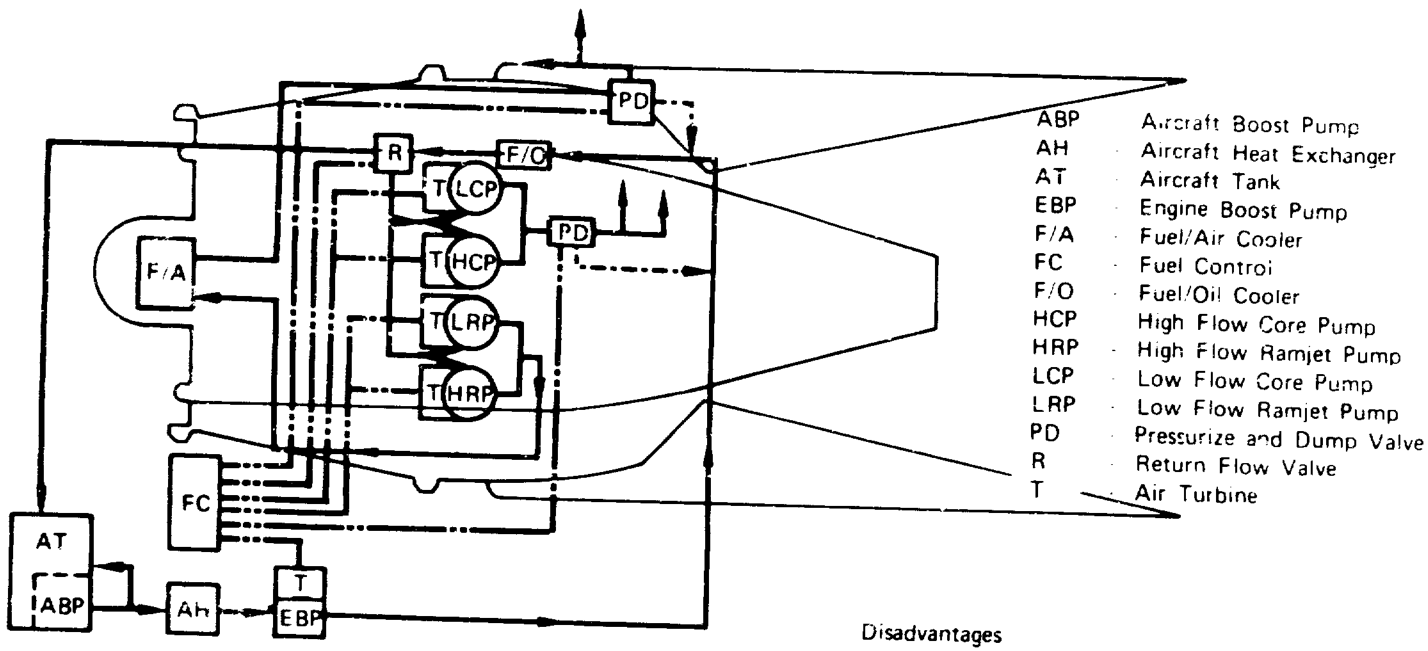
A fuel system alternative offering a more simple control mode than the baseline system is shown in figure 153. Individual pumping systems are provided for the turbojet and ramjet so that the output of each pumping system can be individually controlled to satisfy individual combustor system demand. It also includes redundant boost pumps to provide limited operating capability with either pump malfunctioning. The baseline system was preferred on the basis of lower environmental and pumping heat loads and the fewer number of components that enhance considerations of packaging, weight and volume.



Advantages
- Eliminates oil supply and scavenge pumps
- Core rotation not required for air-oil mist

Disadvantages
- Carbon formation on oil mist tube walls
- High air supply temperature during ramjet mode
- Cooling air requires precooling with fuel

Figure 152. STRJ334B Once-Through Oil Mist Alternate Lubrication System



Advantages

- Direct pump control for turbojet and ramjet flow requirements
- Oil cooling during all operating modes
- Adaptable to common downstream fuel control system

Disadvantages

- High number of components and plumbing with surfaces exposed to high temperature
- High volume of components for sheltering between the core and ramjet
- Engine boost pump and other components may be exposed to secondary air stream
- High fuel pump inlet temperatures
- Inactive systems will become heat generating loops to prevent stagnation

Figure 153. STRJ334B Alternate Fuel System

F. FUEL AND LUBRICANT INFLUENCES

Considerations for selecting fuels and lubricants and the related influences on the engine design were similar to those discussed for the STJ346A engine. Environmental ram air temperatures for the STRJ334B engine are higher by approximately 700°F. However, engine fuel flow is higher, and MCAIR has estimated that the aircraft heat load will be comparable for the two missions (through the use of an insulated structure at the higher Mach number).

1. STRJ334B Engine Fuel Selection

The initial criteria for screening and selection of suitable fuels were whether or not the maximum bulk fuel operating temperature met the thermal stability temperature limits defined for potential STRJ334B engine fuels, table XXIII. Temperatures for the fuel in the engine were computed for aircraft operating conditions that were expected to include the most severe fuel requirements. Based on the definition of the baseline mission, including fuel tank temperature profile, aircraft heat load, and mission flight conditions, the highest estimated fuel temperature was 515°F (figure 100). Cruise at the highest altitude and Mach number of the flight envelope, representing maximum heat load, coupled with minimum heat sink at steady-state conditions, showed a maximum temperature of 550°F based on maximum aircraft/engine interface temperature of 350°F (figure 104). The "worst case" transient condition when engine thrust was reduced to minimum (minimum fuel heat sink) at maximum Mach number (maximum environmental heating) showed a theoretical (no thermal lag) fuel temperature peak of 800°F; however, recirculation of fuel can be used to limit transient temperatures to less than 600°F (figure 112).

Table XXIII. Thermal Stability Temperature Limits for Potential STRJ334B Engine Fuels

Fuel Thermal Stability	Bulk Temperature Limit, °F
JP-5	350
Hydrotreated JP-5	500
JP-7	600

Engine operation was also surveyed over the complete Mach number/altitude operating envelope, with engine thrust at the required part power setting to match steady-state aircraft thrust requirements. Maximum estimated bulk fuel temperatures were 500°F or 550°F for aircraft/engine interface fuel temperatures of 250°F or 350°F, respectively (table XIX). PSJ 162 fuel (Appendix IV) could be considered as a lower cost alternative depending on progress in advancing technology to avoid hydraulic actuation systems.

Based on the above maximum estimated temperatures, JP-7 fuel would have the minimum bulk temperature capability of the selected fuels that would be suitable for use in the STRJ334B engine. Recirculation temperatures up to 400°F could be anticipated resulting in need for a fuel significantly improved from JP-5 in the tendency to form insoluble compounds.

An additional concern leading to the recommendation for use of fuel having thermal stability capability up to 600°F, such as JP-7, is that the STRJ334B baseline design is based on component technology projected to be available in the 1980's, and there are uncertainties in such a projection. The primary area of propulsion system technology having the greatest heat load uncertainty, and, therefore, the greatest potential change in the estimated maximum fuel temperature, is the actuation systems. Accordingly, the influence of using today's actuation technology (hydraulics instead of pneumatics) was evaluated showing that maximum bulk fuel temperatures up to 730°F might result, figure 141. JP-7 may be capable of this temperature on a transient basis at fuel nozzles, where residence time is low, and it can be anticipated that some advancements in technology would be realized to reduce this level.

2. STRJ334B Engine Lubricant Selection

Lubricant operating temperature requirements for the STRJ334B turboramjet engine were estimated and compared with the capabilities of the same candidate lubricants as those surveyed for the STJ346A afterburning turbojet. These lubricants and their corresponding thermal stability bulk temperature limits are shown in table XXIV; Appendix IV lists their properties.

Table XXIV. Lubricant Thermal Stability

Lubricant	Bulk Temperature, °F
MIL-L-27502	425
Hypothetical Ester	500
Polyphenyl Ether	575
Perfluoronated Polyether	650

Based on baseline fuel and lubrication system design and the baseline mission, lubricant temperature would be a maximum of 385°F during maximum thrust conditions at takeoff. For alternate operating conditions at cruise, estimated lubricant temperature of 450°F would occur for 350°F aircraft/engine interface fuel temperature, figure 105. Temperature maximums of 325°F and 367°F were computed for alternate interface fuel temperatures of 150°F and 250°F, respectively. The "worst case" theoretical transient bulk lubricant temperature was computed to be 522°F, figure 115; however, system thermal lag would reduce the actual value, as would fuel recirculation so that this condition would be less severe than the worst steady-state values. Survey of the complete steady-state flight envelope showed the possibility of maximum bulk temperature to 500°F for 350°F aircraft/engine interface fuel temperature. Based on satisfying all these conditions, the STRJ334B would require 500°F hypothetical ester lubricant as a minimum.

The bulk oil temperature did not indicate the highest local temperature, and oil-wetted metal surface temperature up to 558°F was calculated in the front bearing compartment of the STRJ334B engine. The proximity of this temperature to the potential autoignition temperature of the ester lubricants at pressure requires that this factor be given consideration. If margin against ignition hazards were judged to be inadequate the problem could be resolved by use of polyphenyl ether. This could also be necessary if hydraulic actuation were used, figure 144. Dilution would be required to reduce viscosity of polyphenyl ether for low temperature starting.

3. Fuel and Lubricant Influence on STRJ334B Operation and Missions

Fuel and lubrication system design features were found to significantly influence the engine configuration and the capability to operate with a given fuel and lubricant; their effects on engine performance and weight were secondary. Modifications to the initial design included improved fuel distribution manifolds and nozzles, bearing compartment arrangement for the thermal isolation, balancing of lubricant flows, and fuel recirculation systems. When fuel/air coolers were added to use excess fuel heat sink to enhance engine performance, the added weight essentially canceled the potential benefit to the mission. Use of excess fuel heat sink in aircraft systems also appeared to offer little benefit. Because fuel recirculation was needed to circumvent transient fuel overtemperature with any of the candidate fuels, the weight for this system was included for all design alternatives. Furthermore, it was judged that use of a fuel of greater cost and more limited availability was not a good trade for the weight reduction from elimination of fuel recirculation.

Vaporization of water could also be used to reduce transient heat loads. The following example illustrates the effects of using water vaporization to absorb heat equivalent to that to reduce the 515°F spike in fuel temperature for the initial phase of descent for the STRJ334B engine, figure 154. To reduce this peak to the 335°F level just prior to descent would require cooling equivalent to the vaporization of less than 4 lb of water per engine. A boiling water-to-fuel heat exchanger to eliminate this 2-min spike would weigh approximately 30 lb per engine. Since 1 lb of propulsion system weight increases aircraft gross take-off weight (GTOW) 4-1/2 lb and 34 lb would be added to each engine, the GTOW to perform the baseline mission would be increased approximately 300 lb using this approach.

An alternative method to reduce the fuel temperature spike would be to use fuel recirculation, resulting in a 5°F increase in fuel tank temperature. If the required number of anticipated descent-type maneuvers (throttle reduction at high Mach) is small, as for the baseline mission, fuel recirculation would offer less compromise (lower GTOW to achieve mission capabilities). However, if fuel thermal stability limits provide little operating margin, water vaporization should be evaluated for overall cost-effectiveness.

For the baseline mission, ram-air/fuel or ram-air/lubricant coolers were not required, but could be considered for operation at low speeds and higher fuel tank temperatures. A typical ram air cooling system would weigh an estimated 20 to 50 lb. This system would require controls including an air shutoff valve to prevent fuel heating at high Mach numbers. Recent evaluation of the need for the fuel/air cooler on the STRJ334B indicates it may not be required for cooling of the turbojet core during ramjet operation, based on anticipated improvements in materials for the turbojet compressor. Several components, such as these supplementary coolers, would be omitted for simplicity, if possible, but might be required pending definition of all the specifications for these types of engines. This "fine-tuning" of the engine design to match requirements would be reflected in nominal variations in engine weight and should have negligible effects on mission performance, assuming the aircraft design GTOW reflects engine weight with all required features.

Since the aircraft used two engines, each pound in the fuel and lubrication system is worth 2 lb of total propulsion system weight, and a total of 9 lb of aircraft GTOW. Using the factor of 9 lb in GTOW per pound of fuel and lubrication system weight, based on design of the aircraft to satisfy baseline mission requirements, the influence of STRJ334B design alternatives such as supplementary coolers and alternate pumps or actuators can be determined in terms of GTOW (cost).

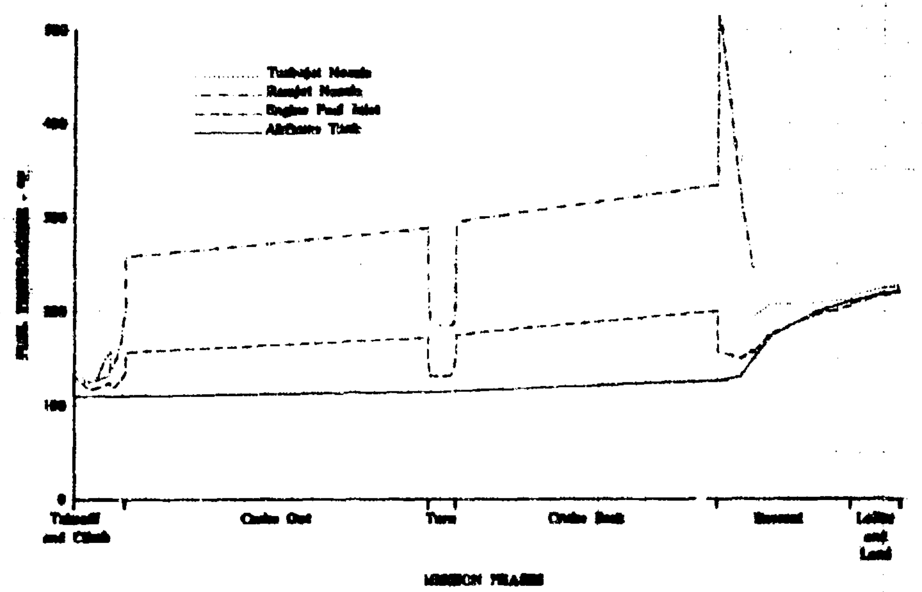


Figure 154. STRJ334B Fuel System Temperatures During the Mission

SECTION V
CONCLUSIONS

- Hydrotreated JP-5 (or equivalent 500°F capability) fuel and MIL-L-27502 lubricant have minimum capabilities necessary to satisfy the Mach 3+ requirements.

- JP-7 fuel and hypothetical 500°F ester lubricant have minimum capabilities to satisfy the Mach 4+ requirements.

- JP-7 fuel and polyphenyl ether (PWA 524) lubricant are the only fluids used in current operating aircraft that could be used for both applications, and these have economic disadvantages (fuel cost, lubricant cost, and operational costs associated with lubricant dilution).

- Continued research and development to improve and/or develop fuels and lubricants is needed for future high Mach number aircraft. Major areas are improved thermal stability, auto-ignition temperature, hot spot stability, and low temperature pumpability for lubricants; and low cost approaches to improve and maintain thermal stability for fuels.

- Continued advancement in the state-or-the-art of fuel and lubrication system components will be necessary. Improvements most needed are: (1) low heat generation actuation systems; (2) bearing compartment design (insulation material, shaft seals, lubricant distribution, structure); and (3) high temperature electronic controls, instrumentation, and servo systems. Required extensions of existing technology are nominal for a Mach 3+ interceptor but represent significant advancement for a Mach 4+ interceptor in order to use the identified fuels and lubricants.

- Successful use of the identified fluids for the study missions will also require:

    - Emphasis on overall aircraft and engine system thermal management
    - Use of sophisticated thermal analyses tools, and supporting design selection tests
    - Recirculation of fuel flow
    - No stagnated fuel nor lubricant
    - Insulated lines and components
    - Design to minimize actuation loads
    - Low heat generation designs

- Thermally isolated bearing compartments
- Use of proper materials and clean handling standards to maintain fluid thermal stability.

- Use of the excess heat sink available in JP-7 fuel to improve the engine cycle (such as fuel cooling of turbine cooling air) does not benefit the overall weapon system.

SECTION VI

RESEARCH RECOMMENDATIONS

A. GENERAL

The results of this program suggest several recommendations for fuels and lubricants research, and for component technology research. The Mach 3+ application could be satisfied by today's technology, but advancements have been defined that could reduce the cost of fuels required; more optimum lubricants should relieve operational constraints and reduce support costs. The Mach 4+ application will require more sophisticated lubricants and advancements in component technology. If component technology is not advanced, a fuel with higher temperature capability would be needed. Research programs should be directed toward providing the most cost effective balance of advanced technology for fuels, lubricants, and system components.

B. FUEL AND LUBRICANT RESEARCH RECOMMENDATIONS

Fuel research is recommended to evaluate alternate approaches to increasing thermal stability of JP-5-type fuels, including use of additives, deoxygenation/ inerting, and hydrotreating. The goal would be to determine the approach offering the lowest life cycle cost to provide a 400 to 500°F thermal stability fuel for the next generation of Mach 3+ aircraft. The approach must continue to satisfy the many established requirements, including low vapor pressure, satisfactory lubricity, and minimum tendency to form insoluble compounds. Thermal stability requirements have been shown to be approximately 350°F for storage, 400°F in components such as valves and heat exchangers, and 500°F in fuel manifolds and nozzles. Reduced cost alternate fuels, such as PSJ 162 (table XLIV), having thermal stability comparable to JP-7 might also be investigated as fuel for the 1980's generation of Mach 4+ aircraft.

Lubricant research is recommended to complete qualification of MIL-L-27502 for Mach 3+ applications and to develop a 500°F ester type lubricant for Mach 4+ applications. Autoignition characteristics should be defined vs typical environmental conditions in bearing compartments and improved, if required, to be consistent with the projected hot spot conditions.

Testing candidate lubricants is recommended using bearing compartment rigs that simulate the extreme temperature environment of high Mach engines as well as their speeds and loads. This testing would be preceded by basic mechanical and thermal development of the rig using polyphenyl ether lubricant and standard laboratory screening tests of candidate lubricants. Oil foaming characteristics, viscosity change, vaporization loss, sludge formation, and performance of bearings and seals under STRJ334B-type engine operating characteristics would be among the factors evaluated.

C. FUEL AND LUBRICATION SYSTEM COMPONENT TECHNOLOGY

The fuel and lubrication system component technology for the STJ346A afterburning turbojet is essentially in hand, based on J58 engine experience (similar engine cycle and operating requirements) and new pump and controls technology developed for the F100-PW-100 turbofan engine. Minimal extensions in technology should satisfy requirements, such as for moderately increased component operating temperature and for an all-electronic control system. Design studies and nominal testing are needed for substantiation. However, the 700°F increase in ram temperature for the STRJ334B engine, compared to the STJ346A, represents a step change in operating temperature requirements for external engine components. Potential problem areas arising from the severe temperature environment have been identified.

Based on today's technology, the electronic computing section of the STRJ334B engine control would have to be maintained at a temperature under 200°F and, if not mounted in a controlled environment in the aircraft, would require a coolant supply at a temperature less than that of the engine fuel supply. In addition, exposure to environmental temperatures exceeding 1200°F will require either improved materials and designs, or insulation and cooling for (1) engine wiring, (2) pressure, temperature, position, and speed sensors, (3) computer output-to-actuator control devices, and (4) variable-geometry actuation systems. Actuation systems were evaluated in greatest detail, since these systems could reduce fuel temperatures approximately 50°F steady-state and 300°F transiently compared to hydraulic actuation systems similar to those used on today's engines.

The baseline STRJ334B fuel and lubrication system design is based on use of bleed-air-driven turbines, powering ball screw actuators through flexible shafts, to position exhaust nozzles and compressor variable geometry. This arrangement would require analytical and experimental investigation to determine if turbines, flexible shafts, and reducing gears could be designed to operate in the extreme environmental temperatures. Uncooled operation is desired, but the alternate of fuel cooling, if needed, should be evaluated to determine suitable cooling techniques and the amount of additional heat load that is entailed. New and innovative approaches for actuation should also be considered to reduce complexity, cost, and heat loads under this recommended research.

Following are additional areas of component technology that are recommended for research programs since advancement in the current state-of-the-art appears to offer significant system gains:

- Insulation for components, piping and bearing compartments to improve durability, insulation properties, and application techniques (the heat retention problem after shutdown should be considered)

- Analytical design study and preliminary design of turboramjet including structural arrangement of bearing supports for thermal isolation while providing adequate strength and vibratory characteristics

- Improved bearing compartment seals to minimize potentially hazardous leakage of high temperature air and to survive the high operating temperatures with adequate life

- The starting system for a gearboxless engine

- Gearboxless accessory drives for pumps, generators, mechanical actuators, etc.

- Control system components with reduced cooling requirements, including (1) interface units from the electronic control to pumps, actuators and valves, (2) control sensors for temperature, pressure, speed, and position, and (3) compressor variable-geometry actuation systems

- Lubricant distribution and scavenge systems suitable for the high temperature bearing compartments

- Environmental bearing compartment (bearing and seal) rig to demonstrate integration of insulation, thermal isolation of structural supports, bearings, seals, lubricant distribution, and lubricant.

APPENDIX I

STJ346A AND STRJ334B FUEL AND LUBRICATION SYSTEM THERMAL ANALYSIS COMPUTER PROGRAM OUTPUT NOMENCLATURE, ENGINE COMPONENT SCHEMATICS, AND CALCULATION PRINTOUT EXAMPLES

Computer programs were prepared for thermal analysis of fuel and lubrication systems for the STRJ334B turboramjet and STJ346A afterburning turbojet engines. The elements of the mathematical model for these programs were similar for both engines, except for the addition of gearbox characteristics for the nearer term STJ346A engine. The programs were designed for flexibility to analyze alternate conditions for the fuel and lubrication systems of both engines, as well as modifications to these systems, such as alternate component arrangements and alternate component characteristics. The mathematical model for each system contained the characteristics of the lubrication, fuel, and air systems and computed heat balances to determine system temperature conditions for a particular set of input operating conditions.

Figure 155 illustrates computer program subroutines used to compute component thermal characteristics within the lubrication system, fuel system, and air system. Each subroutine is represented by a set of three vertical blocks. The upper block lists input items, the middle block identifies the computer program subroutine, and the lower block lists output items. The flow of data from these subroutines is indicated for the initial computational routine to size fuel/air and fuel/oil heat exchangers and determine required oil pump flow capacity and head rise. After sizing these components, the mathematical model of the baseline system can compute component temperature rises and thermal balances for alternative input operating points. Figures 156 and 157 are examples of this process for the STJ346A and STRJ334B. These computations for figures 156 and 157 utilize the same component subroutines shown by figure 155 but follow the computational procedures indicated.

Fuel system input items include time variant aircraft fuel tank temperature, fuel flows (gas generator and augmentor), aircraft heat loads, and hydraulic loads corresponding to the mission profile. Fuel temperature rises are calculated across each component due to environmental heating, internal heat generation (such as pump inefficiency), and heat exchanger loads. Environmental heating of fuel lines is added, and fuel inlet temperature up to the fuel/oil heat exchanger is determined. Computation of fuel temperature rise across the fuel/oil heat exchanger requires an iterative computation of lubrication system heat generation, involving a guess of tank oil temperature and computer iterations, to balance oil system heat generation with heat rejection. The fuel temperature rise to absorb this lubrication heat rejection requirement is then computed. Fuel temperature rise from additional environmental heating is computed and added, determining gas generator nozzle fuel temperature. If this value exceeds the input thermal stability limit of the fuel, the program iterates to determine necessary fuel flow back to aircraft tanks to provide the required auxiliary fuel/oil cooling to achieve

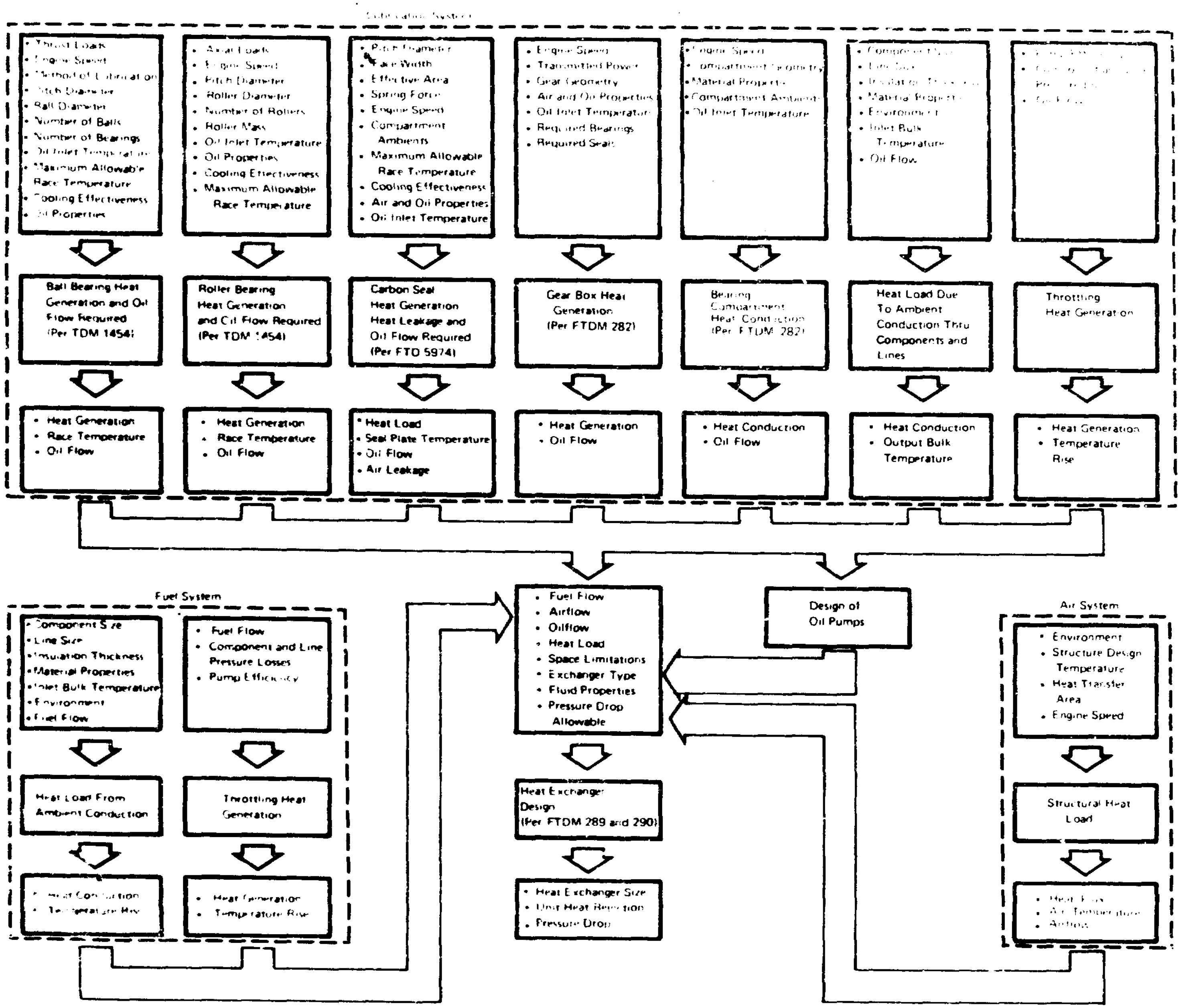


Figure 155. Fuel/Lubrication System Synthesis

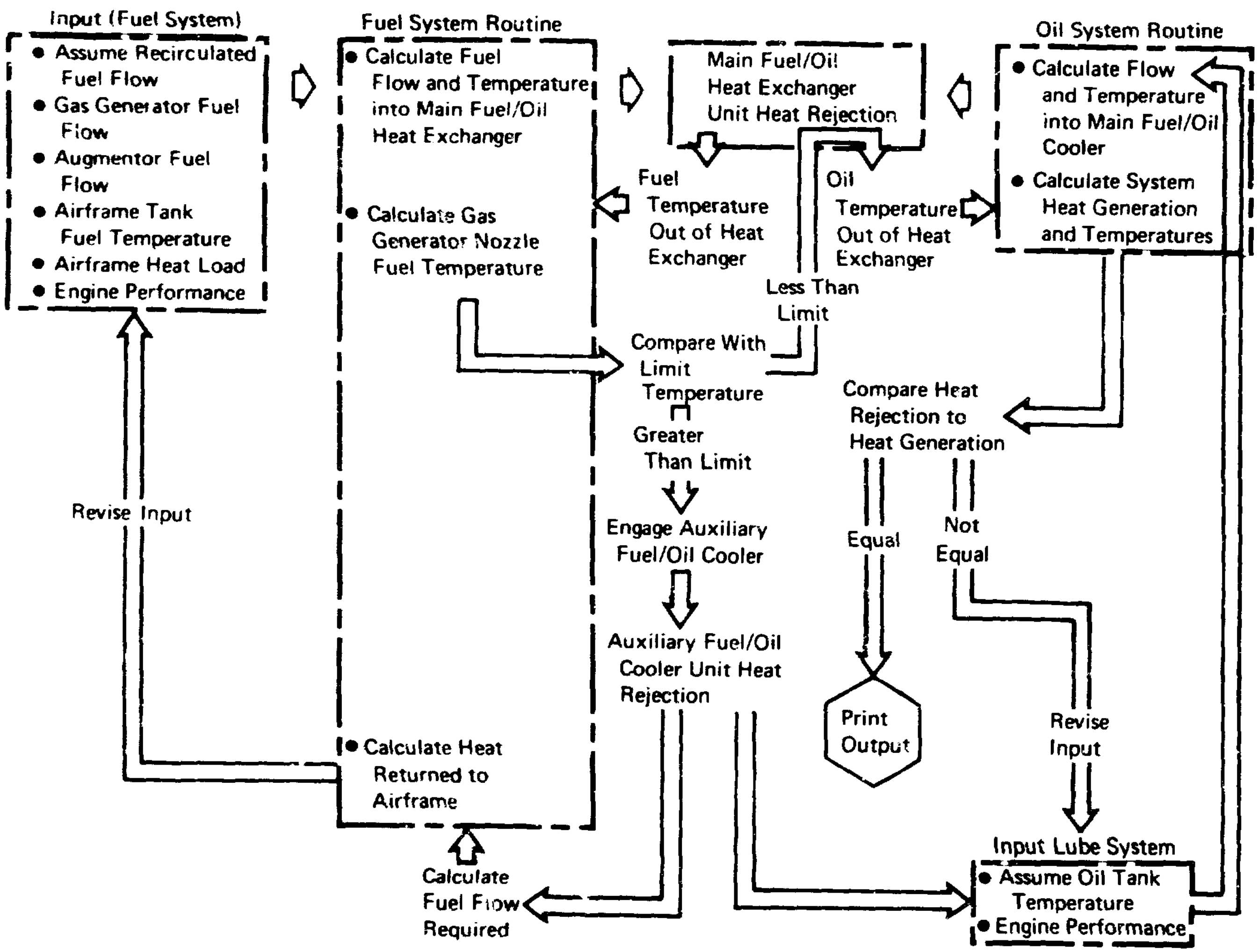


Figure 156. STJ346A Thermal Analysis Flow Chart

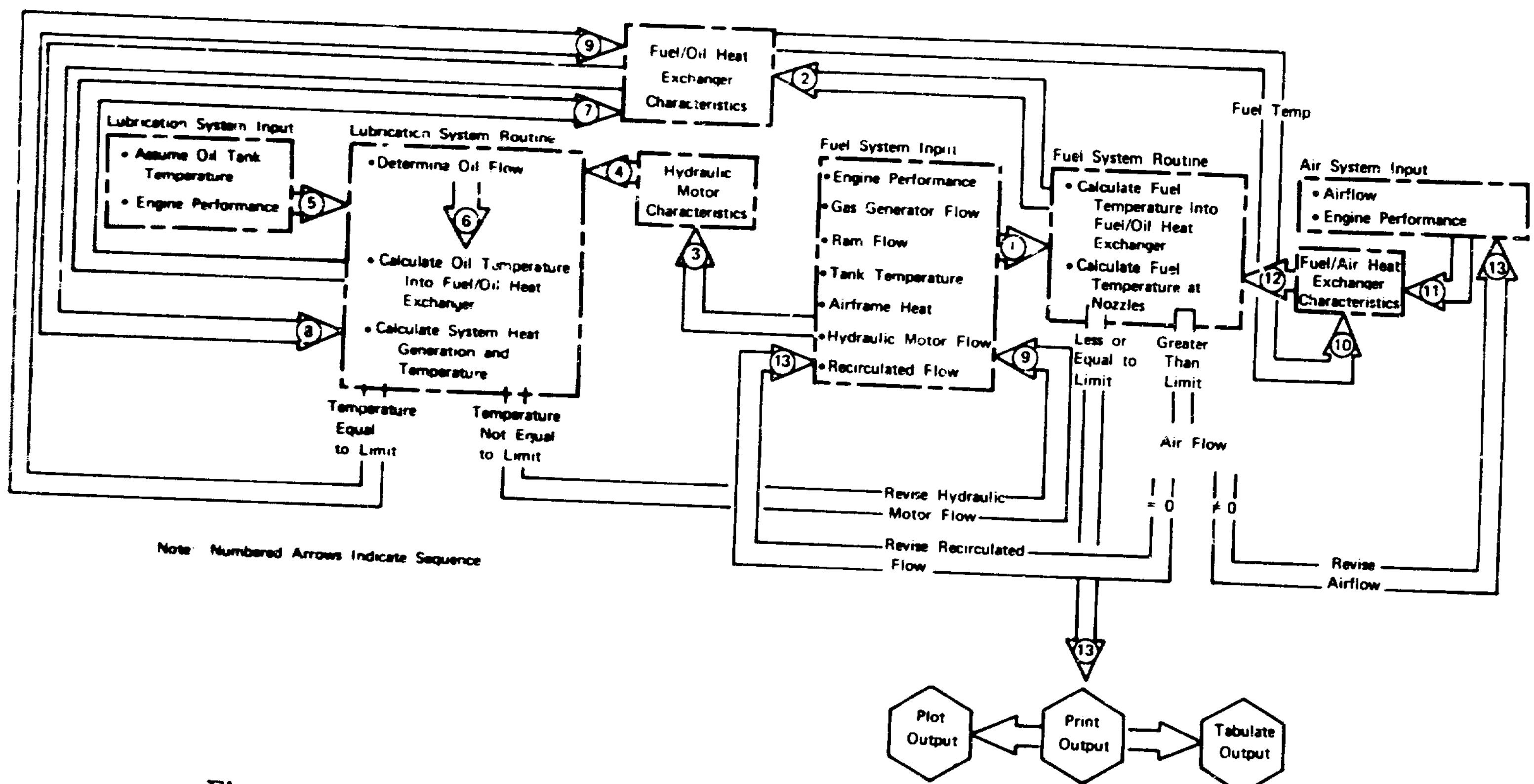


Figure 157. STRJ334B Engine Thermal Analysis Computer Program Flow Chart

acceptable fuel temperature at the fuel nozzle. After all heat balances and limits are satisfied by these computer iterations, the following print output is made as shown below and in tables XXV through XXXV.

- Fuel temperature in and out of each component
- Oil temperature in and out of each component
- Heat due to pump inefficiencies
- Plumbing environmental heat total
- Gearbox and bearing heat generation
- Bearing and seal heat generation
- Bearing compartment environmental heating
- Heat returned to airframe
- Total engine heat generation
- Engine fuel/lubrication system thermal effectiveness
- Input data
- Option to solve for the maximum permissible engine inlet fuel temperature without recirculation of fuel to the airframe. (This logic is not shown in figures 156 or 157, the airframe heat exchanger load is adjusted until fuel temperature is the allowable limit.)

Table XXV. STJ346A Output Nomenclature In Order of Printout

Symbol	Description
Program Input	
&OUT-IN	Input Section
ABCD	Inlet Total Temperature, °R
TT3	Compressor Discharge Temperature, °R
TFTANK	Fuel Tank Temperature, °F
EFGH	Mission Time, min
HROTOR	Engine Speed, rpm
TLIMO	Temperature Limit of Oil, °F
TLIMF	Temperature Limit of Fuel, °F
POP	Percent of PT3 Outside of Seals
QAFR	Airframe Fuel/Oil Heat Exchanger Load, Btu/min
W33P	Percent of Oil Flow to Bearing Compartment No. 2
WS2P	Percent of Oil Flow to Seal Bearing Compartment No. 2
WRBP	Percent of Oil Flow to Roller Bearing
W39P	Percent of Oil Flow to Bearing Compartment No. 1
WS1P	Percent of Oil Flow to Seal Bearing Compartment No. 1
WBBP	Percent of Oil Flow to Ball Bearing
SRATIO	Main Oil Pump/Engine Speed Ratio
PA	Ambient (Altitude) Pressure, psia
PT3	Compressor Discharge Pressure, psia
PT7	Cold Turbine Discharge Pressure, psia
Output - Temperature and Heat (Reference figure 158.)	
&OUTSTM	Common System Temperatures and Heat
T(1), T(2), T(3), ...	System Temperatures Per Schematic, °F
QLIN (1), QLIN (2), ...	System Line Segment Heat Per Schematic, Btu/hr
Output - Heat Transfer	
&OUTBTH	Heat Loads Common to Fuel and Lubrication System
QAFO	Auxiliary Fuel/Oil Cooler Heat, Btu/min
QMFO	Main Fuel/Oil Cooler Heat, Btu/min
Output - Lubrication System Pressures	
&OUTPL	Output Lubrication System Pressure
PMOP	Main Oil Pump Pressure Rise, psi
DPOF	Oil Filter Pressure Drop, psi
DPAO	Auxiliary Fuel/Oil Cooler Pressure Drop, psi
DPMO	Main Fuel/Oil Cooler Pressure Drop, psi
Output - Fuel System Pressures	
&OUTPF	Output Fuel System Pressure
P3	Boost Pump Discharge Pressure, psi
P1	Airframe Fuel Tank Pressurization, psi
DPRGB	Remote Gearbox Heat Exchanger ΔP, psi

Table XXV. STJ346A Output Nomenclature In Order of Printout (Continued)

Symbol	Description
Output - Fuel System Pressures (Concluded)	
DPHEX	Airframe Heat Exchanger ΔP, psi
DPMFO	Main Fuel/Oil Heat Exchanger ΔP, psi
DPAFO	Auxiliary Fuel/Oil Heat Exchanger ΔP, psi
PDBP	Boost Pump Pressure Rise, psi
DPGGN	Gas Generator Nozzle ΔP, psi
DPAN	Augmentor Nozzle ΔP, psi
PDGGP	Gas Generator Pump Rise, psi
PDAP	Augmentor Pump Rise, psi
EFFAP	Augmentor Pump Efficiency
EFFGP	Gas Generator Pump Efficiency
EFFBPH	Boost Pump (High Flow) Efficiency
EFFBPL	Boost Pump (Low Flow) Efficiency
Output - Flowrates (Reference figure 158.)	
&OUTFLW	Output Flows
W(1), W(2), W(3), ...	System Flows {lb/hr for Fuel; lb/min for Oil}
WBPL	Boost Pump Flow (Low)
WBPH	Boost Pump Flow (High)
Output - Lubrication System	
&OUTLUB	Output From Lubrication System
QOP	Main Oil Pump Heat, Btu/min
QOF	Oil Filter Heat, Btu/min
QAO	Auxiliary Fuel/Oil Cooler Heat, Btu/min
QOT	Oil Tank Heat, Btu/hr
DTSP1	Temperature Rise of Scavenge Pump No. 1, °F
DTSP2	Temperature Rise of Scavenge Pump No. 2, °F
T21C	Back Calculated Oil Tank Temperature, °F
QLINT	Total Line Segment Heat, Btu/hr
QMOT	Main Fuel/Oil Cooler Throttling Heat, Btu/min
QSP1	Scavenge Pump No. 1 Heat, Btu/min
QSP2	Scavenge Pump No. 2 Heat, Btu/min
QLUBE	Total Lubrication System Heat, Btu/min
Output - Fuel System	
&OUTFUL	Output From Fuel System
QBP	Boost Pump Heat, Btu/min
QHEX	Airframe Hex Throttling Heat. Btu/min
QGBT	RGB Hex Throttling Heat, Btu/min
QAP	Augmentor Pump Heat, Btu/min
QGGP	Gas Generator Pump Heat, Btu/min
DTAN	Augmentor Nozzle Temperature Rise, °F
QFOT	Main Fuel/Oil Heat Exchanger Throttling Heat, Btu/min

Table XXV. STJ346A Output Nomenclature In Order of Printout (Continued)

Symbol	Description
Output - Fuel System (Concluded)	
DTGGN	Gas Generator Nozzle Temperature Rise, °F
SYSEFF	System Effectiveness
QGGN	Gas Generator Nozzle Heat, Btu/hr
QAN	Augmentor Nozzle Heat, Btu/hr
Output - Horsepower Loads	
&OUTHOR	Output Horsepowers
FPHPLB	Gas Generator Fuel Pump, hp
OPHP	Main Oil Pump, Scavenge Pump, Deaerator, hp
ABPHP	Airframe Boost Pump, hp
ATPHP	Airframe Transfer Pumps, hp
FPHP	Boostpump + Transfer Pumps, hp
GHP	Airframe Generator, hp
HPHP	Airframe Hydraulic Pump, hp
RMGBHP	Remote Gearbox, hp
PO	Pressure Outside Bearing Compartments
PBC	Compartment Pressure
Output - Front Bearing Compartment	
&OUTCN1	Output Bearing Compartment No. 1
WBB	Ball Bearing Oil Flow, lb/min
QBBRG	Ball Bearing Heat Generation, Btu/min
CEFFO	Outer Race Cooling Effectiveness
CEFFIN	Inner Race Cooling Effectiveness
TROUT	Outer Race Temperature, °F
TRIN	Inner Race Temperature, °F
WCS1	Oil Flow to Carbon Seal, lb/min
QCS1	Heat Generation of Carbon Seal, Btu/min
CEFFS1	Carbon Seal Cooling Effectiveness
TSP1	Seal Plate Temperature, °F
T001	Oil Discharge Temperature, °F
WA1	Seal Air Leakage, lb/sec
QSHL1	Seal Leakage Heat, Btu/min
QFF1	Bearing Compartment Front Face Heat, Btu/min
QBF1	Bearing Compartment Back Face Heat, Btu/min
QPA1	Bearing Compartment Peripheral Area Heat, Btu/min
QSC1	Bearing Compartment Shaft Conduction, Btu/min
QTOT1	Total Bearing Compartment No. 1 Heat, Btu/min
TSBBQ	Tower Shaft Ball Bearing Heat Generation, Btu/min
TSRBQ	Tower Shaft Roller Bearing Heat Generation, Btu/min
QGEAR1	Tower Shaft Gearing Heat Generation, Btu/min

Table XXV. STJ346A Output Nomenclature In Order of Printout (Continued)

Symbol	Description
Output - Rear Bearing Compartment	
&OUTCN2	Output Bearing Compartment No. 2
WRB	Roller Bearing Oil Flow, lb/min
QRB	Roller Bearing Heat Generation, Btu/min
EFFO	Bearing Outer Race Effectiveness
EFFIN	Bearing Inner Race Effectiveness
TRO	Outer Race Temperature, °F
TRI	Inner Race Temperature, °F
WCS2	Carbon Seal Oil Flow, lb/min
QCS2	Carbon Seal Heat Generation, Btu/min
CEFFS2	Seal Cooling Effectiveness
TSP2	Seal Plate Temperature, °F
T002	Seal Cooling Oil Discharge Temperature, °F
WA2	Seal Air Leakage, lb/sec
WPR2	Piston Ring Air Leakage, lb/sec
QSHL2	Seal (Total) Leakage Heat, Btu/min
QAF2	Bearing Compartment No. 2 Aft Face Conduction, Btu/min
QAA2	Bearing Compartment No. 2 Section A-A Conduction, Btu/min
QBB2	Bearing Compartment No. 2 Section B-B Conduction, Btu/min
QAB2	Bearing Compartment No. 2 Section A-B Conduction, Btu/min
QBC2	Bearing Compartment No. 2 Seal Support Conduction, Btu/min
QDD2	Bearing Compartment No. 2 Shaft Conduction, Btu/min
QFF2	Bearing Compartment No. 2 Fwd Face Conduction, Btu/min
QTOT2	Bearing Compartment No. 2 Total Heat, Btu/min
Output - Main Gearbox	
&OUTMGB	Main Gearbox Heat Generation
QBRGTM	Total Bearing Heat Generation, Btu/min
QSLTM	Total Seal Heat Generation, Btu/min
QGRTM	Total Gear Heat Generation, Btu/min
QMGB	Total Main Gearbox Heat, Btu/min
Output - Remote Gearbox	
&OUTRGB	Remote Gearbox Heat Generation
QSLTR	Total Seal Heat Generation, Btu/min
QBRGTR	Total Bearing Heat Generation, Btu/min
QGRTR	Total Gear Heat Generation, Btu/min
QRGB	Total Remote Gearbox Heat, Btu/min

Table XXV. STJ346A Output Nomenclature In Order of Printout (Continued)

Symbol	Description
Output - Fuel System Summary	
&OUTSUM	Fuel System Heat Summary
QAFOT	Auxiliary Fuel/Oil Cooler Throttling Heat, Btu/min
QTT	Total Throttling Heat, Btu/min
QFSL	System Total Heat Load, Btu/min
QLINTF	Total Line Heat Transfer, Btu/min
QFR	Heat Returned to Airframe, Btu/min
QGGSP	Gas Generator Potential Heat Sink, Btu/min
QASP	Augmentor Potential Heat Sink, Btu/min
QGGSA	Gas Generator Actual Heat Sink, Btu/min
QASA	Augmentor Actual Heat Sink, Btu/min

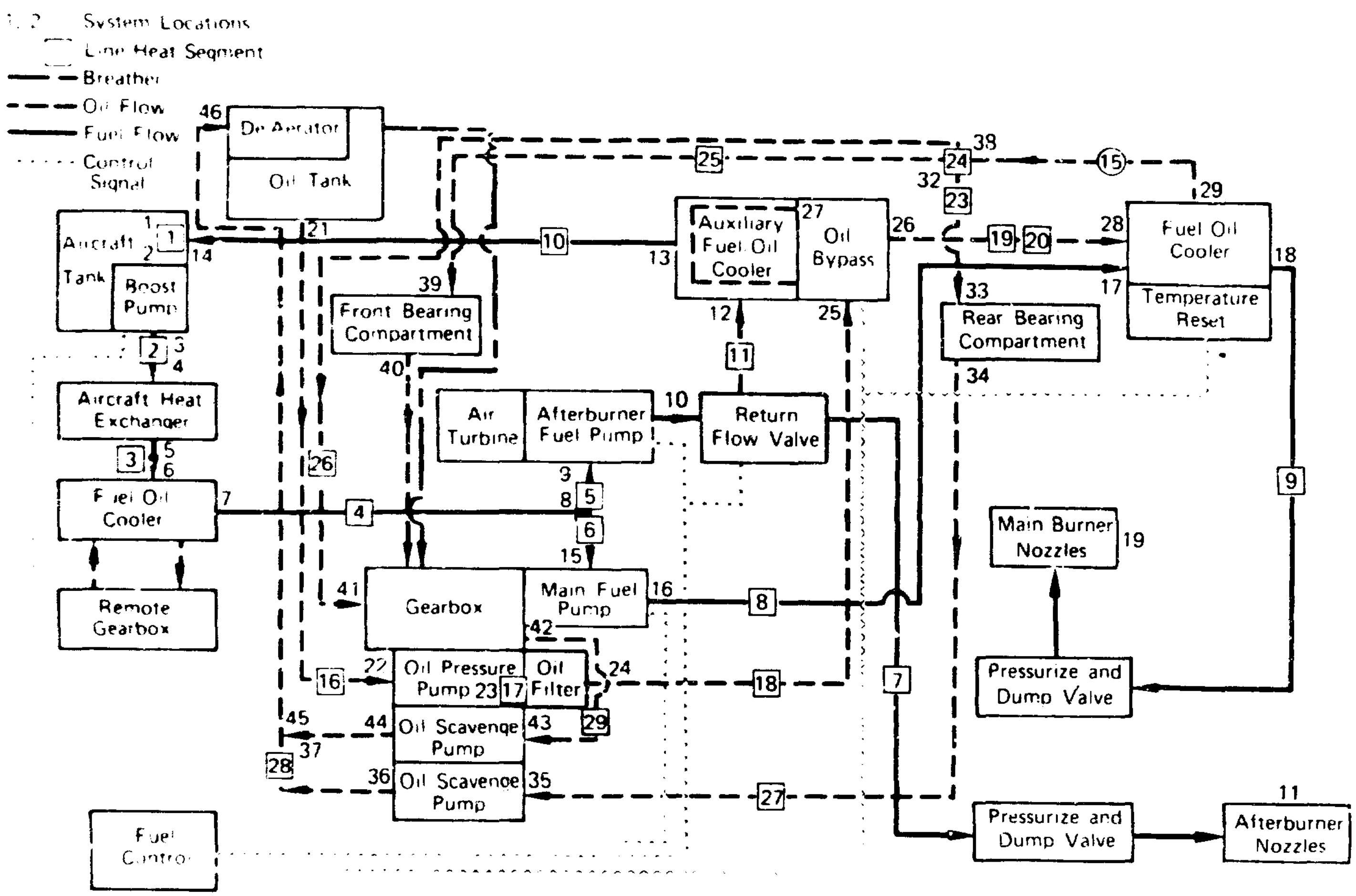


Figure 158. STJ346A Engine Fuel and Lubrication Baseline Systems and Computer Program Designations

Table XXVI. STJ346A Fuel and Lubricant Temperatures and Heat Loads at Takeoff

```
                         STJ346A FUEL AND LUBE SYSTEM THERMAL ANALYSIS  12 /01 /72

                                  F L I G H T   P O I N T   N U M B E R   1

&OUTIN
  ABCD   =              ,  TT3    =  743.000   ,  TFTANK =  110.000  ,  EFGH   =             ,  HROTOR =  8090.00  ,
  TLIMC  =  575.000     ,  TLIMF  =  600.000   ,  PCP    =  .450000  ,  GAFK   =  6700.00    ,  W33P   =  .290000  ,
  WS2P   =  .500000     ,  WRBP   =  .500000   ,  W35P   =  .570000  ,  WS1P   =  .500000    ,  WBBP   =  .500000  ,
  SRATIC =  .464000     ,  PA     =  14.7000   ,  PT5    =  176.400  ,  PT7    =  53.3000    ,
&END
&OUTSIN

  T      =  110.000   ,  110.000   ,  111.392   ,  111.382   ,  125.598   ,
            125.554   ,  126.712   ,  126.699   ,  126.684   ,  128.498   ,
            126.142   ,  127.380   ,  127.382   ,  124.611   ,  126.694   ,
            128.260   ,  128.272   ,  135.384   ,  135.268   ,  .0        ,
            253.213   ,  253.130   ,  253.752   ,  253.752   ,  253.752   ,
            253.721   ,  253.752   ,  253.476   ,  200.000   ,  .0        ,
            199.988   ,  199.988   ,  199.462   ,  242.520   ,  240.684   ,
            240.684   ,  240.684   ,  199.988   ,  199.831   ,  257.416   ,
            199.839   ,  259.248   ,  259.161   ,  259.162   ,  254.274   ,
            254.093   ,  .0        ,  .0        ,  .0        ,  .0        ,
  GLIN   =  .0        ,  -305.773  ,  -1294.91  ,  -394.965  ,  -217.452  ,
            -74.2499  ,  -337.066  ,  -103.444  ,  -302.841  ,  -1227.11  ,
            -534.754  ,  .0        ,  .0        ,  .0        ,  .0        ,
            -155.175  ,  .0        ,  -67.9948  ,  -452.758  ,  .0        ,
            -22.5359  ,  .0        ,  -275.140  ,  .0        ,  -161.216  ,
            -37.4583  ,  -980.541  ,  .0        ,  -114.065  ,  -334.350  ,
            .0        ,  .0        ,  .0        ,  .0        ,  .0        ,
            .0        ,  .0        ,  .0        ,  .0        ,  .0        ,
            .0        ,  .0        ,  .0        ,  .0        ,  .0        ,
            .0        ,  .0        ,  .0        ,  .0        ,  .0        ,
&END
&OUTBTH

  QAFC   =  .0        ,  QMFC   =  1629.76   ,
&END
&OUTPL
  PMOP   =  155.203   ,  DPOF   =  .909753   ,  DPAC   =  .0        ,  DPMO   =  4.25787   ,
&END
&OUTPF
  P3     =  231.225   ,  P1     =  17.7000   ,  DPRGG  =  52.9506   ,  DPHEX  =  60.5739   ,  DPMFO  =  27.5000  ,
  DPAFL  =  .215000   ,  PDBP   =  213.525   ,  DPGGN  =  276.400   ,  DPAN   =  153.300   ,  PDGGP  =  303.900  ,
  PCAP   =  153.300   ,  EFFAP  =  .405000   ,  EFFGP  =  .606776   ,  EFFBPH =  .495563   ,  EFFBPL =  .637475  ,
&END
&OUTFLW

  W      =  60850.0   ,  60650.0   ,  60850.0   ,  23500.0   ,  23500.0   ,
            23500.0   ,  60650.0   ,  60850.0   ,  31250.0   ,  31250.0   ,
            30250.0   ,  1000.00   ,  1000.00   ,  1000.00   ,  29600.0   ,
            29600.0   ,  29600.0   ,  29600.0   ,  29600.0   ,  .0        ,
            69.9695   ,  69.9695   ,  69.9695   ,  69.9695   ,  .0        ,
            69.9695   ,  .0        ,  69.9695   ,  69.9695   ,  .0        ,
            69.9695   ,  69.9695   ,  20.2970   ,  69.9695   ,  20.2970   ,
            20.2970   ,  20.2970   ,  49.6925   ,  20.2970   ,  39.8940   ,
                                                  39.6940   ,
```

Table XXVI. STJ346A Fuel and Lubricant Temperatures and Heat Loads at Takeoff (Continued)

```
           9.79654     ,              49.6925     ,              49.6925     ,              49.6925     ,              69.9895     ,
           69.9695     ,              69.9695     ,              .0          ,              .0          ,              .0          ,
 WFFL    = 30000.0     , WFPH     =   30650.0     ,
&END
&OUTLUB
 QOP     = 19.2066     , QCF      =   .161663     , QAC     =    .0          , QDT     =    -26.8741    , DTSP1   =    .113066E-02,
 DTSP2   = .170265E-02, TRIL      =   253.222     , QLINT   =    -2601.23    , QMOT    =    .782480     , QSP1    =    .248224E-01,
 QSP2    = .151445E-02, CLUBE     =   1642.05     ,
&END
&OUTFUL
 QEP     = 656.519     , QHEX     =   90.3523     , QGBT    =    79.6606     , QAP     =    450.509     , QGGP    =    373.152     ,
 DTAN    = -.332716    , QFCT     =   52.1503     , DTGGN   =    -.115372    , SYSEFF  =    .257210E-01, QGGN    =    -570.238    ,
 QAN     = -610.693    ,
&END
&OUTHCK
 FPMPLE  = 22.3605     , LPHP     =   2.11570     , ALPHP   =    34.6834     , ATPHP   =    6.97667     , FPHP    =    41.8660     ,
 GMP     = 220.000     , MFHP     =   150.000     , RMGBHP  =    421.851     , PO      =    79.3800     , PBC     =    39.6900     ,
&END
&OUTCN1
 WBB     = 19.9470     , GBBRG    =   593.495     , CEFFC   =    .727144     , CEFFIN  =    1.29004     , TROUT   =    249.005     ,
 TRIN    = 267.072     , WCS1     =   19.9470     , QCS1    =    132.468     , CEFFS1  =    1.50000     , TSP1    =    222.472     ,
 TCO1    = 214.925     , WA1      =   .176267E-02, QSHL1   =    14.2304     , QFF1    =    -.555979    , QBF1    =    1.25476     ,
 QPA1    = -3.13226    , QSC1     =   23.2055     , QTO11   =    1001.18     , TSBBG   =    33.9925     , TSRBG   =    11.4859     ,
 QGEAR1  = 194.734     ,
&END
&OUTCN2
 WRE     = 10.1465     , CRB      =   157.462     , EFFC    =    3.87372     , EFFIN   =    2.90214     , TRO     =    336.112     ,
 TRI     = 301.839     , WCS2     =   10.1465     , QCS2    =    142.421     , CEFFS2  =    1.50000     , TSP2    =    247.316     ,
 TO2     = 231.365     , WA2      =   .182616E-02, WPR2    =    .609367E-03, QSHL2   =    19.0640     , QAF2    =    .309314E-01,
 QAA2    = .733067E-01, QBB2      =   .487016E-01, QAB2    =    46.3670     , QBC2    =    10.1847     , QDD2    =    2.48994     ,
 QFF2    = 1.36230     , QTOT2    =   379.563     ,
&END
&OUTMGB
 QBRGTM  = 95.1655     , QSLTM    =   18.5506     , QGRTM   =    197.623     , CMGB    =    311.359     ,
&END
&OUTRGB
 QSLTR   = 63.1415     , QLRGTR   =   35.3750     , QGRTR   =    381.382     , QRGB    =    479.898     ,
&END
&OUTSUM
 QAFCT   = 62.6053     , CTT      =   132.577     , QFSL    =    10372.6     , QLINTF  =    -4792.56    , QFK     =    116.048     ,
 QGGSP   = 155.163     , QASP     =   156.693     , QGGSA   =    5.90762     , CASA    =    4.31107     ,
&END
```

Table XXVII. STJ346A Fuel and Lubricant Temperatures and Heat Loads at Start of Cruise Out

```
                                     F L I G H T   P O I N T   N U M B E R   15

&OUTIN
  ABCD   =              , TT3    =  1155.00   , TFTANK =  110.000   , EFGH   =              , HROTOR =  8668.00   ,
  TLINO  =  575.000     , TLINF  =  600.000   , PGP    =  .450000   , QAFR   =  6700.00     , W33P   =  .290000   ,
  WS2P   =  .500000     , WRBP   =  .500000   , W39P   =  .570000   , WS1P   =  .500000     , WBBP   =  .500000   ,
  SRATIO =  .464000     , PA     =            , PT3    =  334.700   , PT7    =  77.2000     ,
&END
&OUTSTR

  T      =  110.000     ,           110.000   ,           111.710   ,           111.740     ,           119.379   ,
            119.475     ,           120.218   ,           120.247   ,           120.273     ,           122.383   ,
            122.991     ,           126.600   ,           126.601   ,           136.241     ,           120.261   ,
            122.412     ,           122.430   ,           128.967   ,           129.775     ,           .0        ,
            266.833     ,           266.880   ,           267.577   ,           267.577     ,           267.577   ,
            267.603     ,           267.577   ,           267.739   ,           200.000     ,           .0        ,
            200.015     ,           200.015   ,           200.658   ,           260.760     ,           261.909   ,
            261.909     ,           261.909   ,           200.015   ,           200.207     ,           267.193   ,
            200.197     ,           267.766   ,           267.813   ,           267.814     ,           266.251   ,
            266.352     ,           .0        ,           .0        ,           .0          ,           .0        ,
  QLIN   =  .0          ,           1586.42   ,           5140.05   ,           1537.15     ,           846.443   ,
            288.628     ,           1268.01   ,           389.746   ,           1009.13     ,           4595.95   ,
            1997.66     ,           .0        ,           .0        ,           .0          ,           .0        ,
            93.1869     ,           .0        ,           40.4732   ,           269.504     ,           .0        ,
            29.3314     ,           .0        ,           357.964   ,           .0          ,           209.707   ,
            48.7234     ,           657.912   ,           .0        ,           65.8988     ,           200.681   ,
            .0          ,           .0        ,           .0        ,           .0          ,           .0        ,
            .0          ,           .0        ,           .0        ,           .0          ,           .0        ,
            .0          ,           .0        ,           .0        ,           .0          ,           .0        ,
            .0          ,           .0        ,           .0        ,           .0          ,           .0        ,
&END
&OUTBTH

  QAFO   =  .0          , QMFO   =  2201.06   ,
&END
&OUTPL
  PMOP   =  174.034     , DPOF   =  1.01438   , DPAO   =  .0        , DPMO   =  4.74332     ,
&END
&OUTPF
  P3     =  220.025     , P1     =  6.50000   , DPRGB  =  52.9506   , DPHEX  =  60.5739     , DPMFO  =  27.5000   ,
  DPAFC  =  .215000     , PDBP   =  213.525   , DPGGN  =  434.700   , DPAN   =  177.200     , PDGGP  =  462.200   ,
  PDAP   =  177.200     , EFFAP  =  .405000   , EFFGP  =  .635240   , EFFBPH =  .472855     , EFFBPL =  .626742   ,
&END
&OUTFLW

  W      =  113761.     ,           113761.   ,           113761.   ,           23500.0     ,           23500.0   ,
            23500.0     ,           113761.   ,           113761.   ,           69276.0     ,           69278.0   ,
            68276.0     ,           1000.00   ,           1000.00   ,           1000.00     ,           44483.0   ,
            44483.0     ,           44483.0   ,           44483.0   ,           44483.0     ,           .0        ,
            74.3835     ,           74.3835   ,           74.3835   ,           74.3835     ,           .0        ,
            74.3835     ,           .0        ,           74.3835   ,           74.3835     ,           .0        ,
            74.3835     ,           74.3835   ,           21.5712   ,           21.5712     ,           21.5712   ,
            21.5712     ,           21.5712   ,           52.8123   ,           42.3986     ,           42.3986   ,
```

Table XXVII. STJ346A Fuel and Lubricant Temperatures and Heat Loa.ls at Start of Cruise Out (Continued)

```
              10.4137     ,                52.6123    ,              52.8123    ,              52.6123     ,             74.3835     ,
              74.3835     ,                74.3835    ,              .0         ,              .0          ,             .0          ,
  WBPL    =   30000.0     ,  WBPH    =     83761.0    ,
&END
&OUTLUB
  QOP     =   22.9995     ,  QOF     =     .201135    ,  QAC     =   .0         ,  QOT     =   16.0436     ,  DTSP1   =   .129330E-02,
  DTSP2   =   .192057E-03,   T21C    =     266.839    ,  QLINT   =   1973.36    ,  QMOT    =   .928852     ,  QSP1    =   .303382E-01,
  QSP2    =   .183255E-02,   QLUBE   =     2229.35    ,
&END
&OUTFUL
  QBP     =   1506.54     ,  QHEX    =     90.3701    ,  QGBT    =   79.3338    ,  QAP     =   1150.35     ,  QGGP    =   753.010     ,
  DTAN    =   .569504     ,  QFCT    =     76.1167    ,  DTGGN   =   .808197    ,  SYSEFF  =   .155078E-01,  QGGN    =   2105.39     ,
  QAN     =   2321.09     ,
&END
&OUTHOR
  FPHPLB  =   48.7026     ,  OPHP    =     2.34004    ,  ABPHP   =   71.8025    ,  ATPHP   =   14.3605     ,  FPHP    =   86.1630     ,
  GHP     =   220.000     ,  HPHP    =     150.000    ,  RMGBHP  =   468.437    ,  PO      =   150.615     ,  PBC     =   75.3075     ,
&END
&OUTCN1
  WBB     =   21.1993     ,  QBBRG   =     662.558    ,  CEFFO   =   .696930    ,  CEFFIN  =   1.23988     ,  TROUT   =   249.706     ,
  TRIN    =   288.269     ,  WCS1    =     21.1993    ,  QCS1    =   197.750    ,  CEFFS1  =   1.50000     ,  TSP1    =   232.004     ,
  TOO1    =   221.405     ,  WA1     =     .362336E-02,  QSHL1   =   54.3021    ,  QFF1    =   .720105     ,  QBF1    =   2.20565     ,
  QPA1    =   4.05693     ,  QSC1    =     41.0255    ,  QTOT1   =   1240.58    ,  TSBBQ   =   38.3856     ,  TSRBQ   =   13.1879     ,
  QGEAR1  =   226.286     ,
&END
&OUTCN2
  WRB     =   10.7856     ,  QRB     =     175.792    ,  EFFO    =   3.78771    ,  EFFIN   =   2.84207     ,  TRO     =   340.924     ,
  TRI     =   305.905     ,  WCS2    =     10.7856    ,  QCS2    =   212.588    ,  CEFFS2  =   1.50000     ,  TSP2    =   267.833     ,
  TOO2    =   245.441     ,  WA2     =     .375755E-02,  WPR2    =   .997924E-03,  QSHL2   =   69.4340     ,  QAF2    =   .595800E-01,
  QAA2    =   .130325     ,  QBB2    =     .865792E-01,  QAB2    =   82.4644    ,  QBC2    =   18.1059     ,  QDD2    =   4.42649     ,
  QFF2    =   2.45738     ,  QTOT2   =     565.543    ,
&END
&OUTMGB
  QBRGTM  =   101.111     ,  QSLTM   =     19.8760    ,  QGRTM   =   229.152    ,  QMGB    =   350.138     ,
&END
&OUTRGB
  QSLTR   =   67.6527     ,  QBRGTR  =     39.5134    ,  QGRTR   =   478.227    ,  QRGB    =   585.393
&END
&OUTSUM
  QAFCT   =   .825696     ,  QTT     =     158.278    ,  QFSL    =   13088.8    ,  QLINTF  =   18659.2     ,  QFR     =   207.416     ,
  QGGSP   =   233.360     ,  QASP    =     358.190    ,  QGGSA   =   6.91864    ,  QASA    =   6.94036     ,
&END
```

Table XXVIII. STJ346A Fuel and Lubricant Temperatures and Heat Loads at Start of Cruise Back

```
                          F L I G H T   P O I N T   N U M B E R   31

&OUTIN
 ABCD   =                 , TT3    =  1492.00     , TFTANK =  117.500   , EFGH   =              , HROTOR =  7300.00  ,
 TLIMO  =  575.000        , TLIMF  =  600.000     , POP    =  .450000   , QAFR   =  6700.00     , W33P   =  .290000  ,
 WS2P   =  .500000        , WRBP   =  .500000     , W39P   =  .570000   , WS1P   =  .500000     , WBBP   =  .500000  ,
 SRATIO =  .464000        , PA     =              , PT3    =  63.0000   , PT7    =  19.4000     ,
&END
&OUTSTM

 T      =  117.500        ,           117.500     ,           118.128   ,           119.341     ,           222.934  ,
           225.990        ,           231.552     ,           232.447   ,           236.024     ,           236.051  ,
           .0             ,           245.479     ,           245.480   ,           266.947     ,           232.643  ,
           235.152        ,           235.416     ,           263.356   ,           272.582     ,           .0       ,
           309.234        ,           309.531     ,           309.977   ,           309.977     ,           309.977  ,
           310.110        ,           309.977     ,           310.973   ,           246.421     ,           .0       ,
           246.488        ,           246.488     ,           249.335   ,           300.653     ,           307.651  ,
           307.651        ,           307.651     ,           246.488   ,           247.336     ,           300.621  ,
           247.290        ,           302.956     ,           303.258   ,           303.259     ,           304.412  ,
           305.054        ,           .0          ,           .0        ,           .0          ,           .0       ,
 QLIN   =  .0             ,           4357.48     ,           12746.4   ,           3777.77     ,           1979.96  ,
           718.220        ,           .0          ,           973.952   ,           2480.68     ,           12085.0  ,
           5243.12        ,           .0          ,           .0        ,           .0          ,           .0       ,
           467.865        ,           .0          ,           204.305   ,           1360.38     ,           .0       ,
           103.834        ,           .0          ,           1265.60   ,           .0          ,           741.053  ,
           172.149        ,           3186.18     ,           .0        ,           337.027     ,           1010.70  ,
           .0             ,           .0          ,           .0        ,           .0          ,           .0       ,
           .0             ,           .0          ,           .0        ,           .0          ,           .0       ,
           .0             ,           .0          ,           .0        ,           .0          ,           .0       ,
           .0             ,           .0          ,           .0        ,           .0          ,           .0       ,
&END
&OUTBTH

 QAFO   =  .0             , QMFO   =  1673.41     ,
&END
&OUTPL
 PMOP   =  111.633        , DPOF   =  .650840     , DPAC   =  .0        , DPMO   =  3.08111     ,
&END
&OUTPF
 P3     =  120.464        , P1     =  3.43000     , DPRGB  =  10.4665   , DPHEX  =  6.56777     , DPMFO  =  4.98886  ,
 DPAFO  =  .215000        , PDBP   =  117.034     , DPGGN  =  163.000   , DPAN   =  119.400     , PDGGP  =  167.989  ,
 PDAP   =  .215000        , EFFAP  =  .562499E-01, EFFGP  =  .330448   , EFFBPH =  .422452     , EFFBPL =  .602341  ,
&END
&OUTFLW

 W      =  7630.00        ,           7630.00     ,           7630.00   ,           7630.00     ,           7630.00  ,
           7630.00        ,           7630.00     ,           7630.00   ,           1000.00     ,           1000.00  ,
           .0             ,           1000.00     ,           1000.00   ,           1000.00     ,           6630.00  ,
           6630.00        ,           6630.00     ,           6630.00   ,           6630.00     ,           .0       ,
           58.1549        ,           58.1549     ,           58.1549   ,           58.1549     ,           .0       ,
           58.1549        ,           .0          ,           58.1549   ,           58.1549     ,           .0       ,
           58.1549        ,           58.1549     ,           16.8649   ,           16.8649     ,           16.8649  ,
           16.8649        ,           16.8649     ,           41.2900   ,           33.1483     ,           33.1483  ,
```

Table XXVIII. STJ346A Fuel and Lubricant Temperatures and Heat Loads at Start of Cruise Back (Continued)

```
            3.14169      ,              41.2900      ,            41.2900     ,              41.2900     ,              58.1549      ,
            58.1549      ,              58.1549      ,            .0          ,              .0          ,              .0           ,
 WBPL    =  7630.00      ,  WBPH     =  .0           ,
&END
&OUTLUB
 QOP     =  11.7204      ,  QOF      =  .102516      ,  QAC     =  .0          ,  QOT     =  79.6273     ,  DTSP1   =  .786901E-03,
 DTSP2   =  .120605E-03, T/IC     =  308.092      ,  QLINT   =  8849.08     ,  QMOT    =  .479642     ,  QSP1    =  .146352E-01,
 QSP2    =  .919461E-03, QLUBE    =  1669.78      ,
&END
&OUTFUL
 QBP     =  37.5451      ,  QHEX     =  3.19470      ,  QGBT    =  5.40926     ,  QAP     =  .245781     ,  QGGP    =  153.456      ,
 DTAN    =  .0           ,  QFOT     =  2.25286      ,  DTGGN   =  9.22563     ,  SYSEFF  =  .235249     ,  QGGN    =  4923.32      ,
 QAN     =  .0           ,
&END
&OUTHOR
 FPHPLB  =  5.40859      ,  DPHP     =  1.69056      ,  ABPHP   =  2.22477     ,  ATPHP   =  .444954     ,  FPHP    =  2.66972      ,
 GHP     =  220.000      ,  HPHP     =  150.000      ,  RMGBHP  =  380.641     ,  PO      =  28.3500     ,  PBC     =  14.1750      ,
&END
&OUTCN1
 WBB     =  16.5741      ,  QBBRG    =  417.332      ,  CEFFO   =  .772195     ,  CEFFIN  =  1.36229     ,  TROUT   =  290.614      ,
 TRIN    =  323.686      ,  WCS1     =  16.5741      ,  QCS1    =  85.8564     ,  CEFFS1  =  1.50000     ,  TSP1    =  264.631      ,
 TOO1    =  255.666      ,  WA1      =  .494260E-03, QSHL1   =  10.0993     ,  QFF1    =  2.50811     ,  QBF1    =  2.87527      ,
 CPA1    =  14.1302      ,  QSC1     =  54.1883      ,  QTOT1   =  785.492     ,  TSBBQ   =  19.7056     ,  TSRBQ   =  9.43274      ,
 QGEAR1  =  169.366      ,
&END
&OUTCM2
 WRB     =  8.43246      ,  QRB      =  134.641      ,  EFFO    =  4.00702     ,  EFFIN   =  2.99523     ,  TRO     =  391.618      ,
 TRI     =  355.691      ,  WCS2     =  8.43246      ,  QCS2    =  92.3210     ,  CEFFS2  =  1.50000     ,  TSP2    =  285.856      ,
 TOO2    =  273.682      ,  WA2      =  .512566E-03, WPR2    =  .170855E-03, QSHL2   =  13.7966     ,  QAF2    =  .796870E-01,
 QAA2    =  .174565      ,  GBB2     =  .115969      ,  QAB2    =  110.458     ,  QBC2    =  24.2521     ,  QDD2    =  5.92910      ,
 QFF2    =  3.29156      ,  QTOT2    =  385.059      ,
&END
&OUTMGB
 QBRGTM  =  70.9132      ,  QSLTM    =  16.7392      ,  QGRTM   =  172.143     ,  QMGB    =  259.795     ,
&END
&OUTRGB
 QSLTR   =  56.9756      ,  QBRGTK   =  30.1112      ,  QGRTR   =  295.713     ,  QRGB    =  382.800     ,
&END
&OUTSUM
 QAFOT   =  .883877      ,  QTT      =  8.54600      ,  QFSL    =  9029.06     ,  QLINTF  =  44362.6     ,  QFR     =  1306.07      ,
 CGGSP   =  34.3939      ,  CASP     =  .0           ,  QGGSA   =  9.02075     ,  CASA    =  .0          ,
&END
```

Table XXIX. STJ346A Fuel and Lubricant Temperatures and Heat Loads at Descent

```
                                   STJ346A FUEL AND LUBE SYSTEM THERMAL ANALYSIS  12 /01 /72

                                          F L I G H T   P O I N T   N U M B E R   35
&OUTIN
  ABCD    =  320.000    , TT3    =  758.000     , TFTANK =  161.000   , EFGH   =  46.6300   , HROTOR =  6210.00   ,
  TLIMC   =  575.000    , TLIMF  =  600.000     , PUP    =  .450000   , QAFR   =  .0        , W33P   =  .290000   ,
  WS.P    =  .500000    , WRBP   =  .500000     , W39P   =  .570000   , WS1P   =  .500000   , WBBP   =  .500000   ,
  SRATIC  =  .464000    , PA     =  .540000     , PT3    =  17.5000   , PT7    =  3.90000   ,
&END
&OUTSTM

  T       =  181.000    ,           181.000     ,           181.476   ,           182.173   ,           182.177   ,
             184.465    ,           204.967     ,           205.551   ,           206.189   ,           206.217   ,
             .0         ,           207.902     ,           207.903   ,           211.771   ,           205.760   ,
             213.583    ,           213.845     ,           323.309   ,           325.603   ,           .0        ,
             341.781    ,           341.766     ,           342.076   ,           342.076   ,           342.076   ,
             342.073    ,           342.076     ,           342.033   ,           294.078   ,           .0        ,
             294.081    ,           294.081     ,           294.218   ,           330.613   ,           330.461   ,
             330.461    ,           330.461     ,           294.081   ,           294.122   ,           340.978   ,
             294.120    ,           345.854     ,           345.838   ,           345.838   ,           341.872   ,
             341.843    ,           .0          ,           .0        ,           .0        ,           .0        ,
  QLIN    =  .0         ,           737.558     ,           2446.66   ,           616.835   ,           340.800   ,
             116.760    ,           .0          ,           148.097   ,           -12.5500  ,           2071.77   ,
             900.616    ,           .0          ,           .0        ,           .0        ,           .0        ,
             -17.4776   ,           .0          ,           -7.74486  ,           -51.5665  ,           .0        ,
             4.16951    ,           .0          ,           50.8363   ,           .0        ,           29.7538   ,
             6.91715    ,           -57.1293    ,           .0        ,           -14.7928  ,           -37.6087  ,
             .0         ,           .0          ,           .0        ,           .0        ,           .0        ,
             .0         ,           .0          ,           .0        ,           .0        ,           .0        ,
             .0         ,           .0          ,           .0        ,           .0        ,           .0        ,
             .0         ,           .0          ,           .0        ,           .0        ,           .0        ,
&END
&OUTGTM

  GAFO    =  .0         , UMFO   =  1034.66     ,
&END
&OUTPL
  PMCP    =  77.2454    , DPOF   =  .452790     , DPAC   =  .0        , DPMO   =  2.18195   ,
&END
&OUTPF
  P3      =  104.856    , P1     =  3.54000     , DPKGE  =  .766228   , DPHEX  =  .529812   , DPMFO  =  .177553   ,
  DPAFC   =  .215000    , PLBP   =  101.316     , DPGGN  =  117.500   , DPAN   =  103.900   , PDGGP  =  117.678   ,
  PDAP    =  .215000    , EFFAP  =  .562499E-01, EFFGP  =  .101605   , EFFBPH =  .456460   , EFFBPL =  .619938   ,
&END
&OUTFLW

  W       =  2050.00    ,           2050.00     ,           2050.00   ,           2050.00   ,           2050.00   ,
             2050.00    ,           2050.00     ,           2050.00   ,           1000.00   ,           1000.00   ,
             .0         ,           1000.00     ,           1000.00   ,           1000.00   ,           1050.00   ,
             1050.00    ,           1050.00     ,           1050.00   ,           1050.00   ,           .0        ,
             47.5846    ,           47.5846     ,           47.5848   ,           47.5848   ,           .0        ,
             47.5846    ,           .0          ,           47.5846   ,           47.5846   ,           .0        ,
             47.5846    ,           47.5846     ,           13.7996   ,           13.7996   ,           13.7996   ,
             13.7996    ,           13.7996     ,           33.7852   ,           27.1233   ,           27.1233   ,
```

Table XXIX. STJ346A Fuel and Lubricant Temperatures and Heat Loads at Descent (Continued)

```
               6.66186     ,               33.7652     ,             33.7652     ,             33.7852     ,             47.5848     ,
               47.5646     ,               47.5846     ,             .0          ,             .0          ,             .0          ,
   WBPL    =   2050.00     ,  WFPH    =    .0          ,
 &END
 &OUTLUB
   QOP     =   6.71603     ,  QCF     =    .590757E-01,  QAC     =   .0          ,  QOT     =   -3.00429    ,  DTSP1   =   .666814E-03,
   DTSP2   =   .114593E-03,   TAIC    =    341.705     ,  QLINT   =   -94.6432    ,  QMOT    =   .262063     ,  QSP1    =   .103357E-01,
   QSP2    =   .720728E-03,   QLUBE   =    1041. 2     ,
 &END
 &OUTFUL
   QBP     =   6.40330     ,  QHEX    =    .717264E-01,  QGBT    =   .106561     ,  QAP     =   .241533     ,  QGGP    =   73.1362     ,
   DTAN    =   .0          ,  QFCT    =    .125366E-01,  DTGGN   =   2.29370     ,  SYSEFF  =   .914398E-01,  QGGN    =   5.48315     ,
   QAN     =   .0          ,
 &END
 &OUTHOR
   FPHPLB  =   1.92699     ,  QPHP    =    1.39580     ,  ABPHP   =   .521001     ,  ATPHP   =   .104200     ,  FPHP    =   .625201     ,
   QHP     =   220.000     ,  HPHP    =    150.000     ,  RMGBHP  =   376.491     ,  PO      =   7.87500     ,  PBC     =   3.93750     ,
 &END
 &OUTCN1
   WBB     =   13.5617     ,  QLBRG   =    305.939     ,  CEFFC   =   .854261     ,  CEFFIN  =   1.48495     ,  TROUT   =   336.159     ,
   TRIN    =   367.192     ,  WCS1    =    13.5617     ,  QCS1    =   61.5426     ,  CEFFS1  =   1.50000     ,  TSP1    =   308.969     ,
   TCO1    =   304.020     ,  WA1     =    .173606E-03,  QSHL1   =   1.20844     ,  QFF1    =   .101946     ,  QBF1    =   1.07160     ,
   CPA1    =   .574343     ,  CSC1    =    19.9495     ,  QTOT1   =   575.983     ,  TSBBG   =   11.7338     ,  TSRBQ   =   7.06442     ,
   CGEAR1  =   166.799     ,
 &END
 &OUTCN2
   WRB     =   6.69979     ,  QRB     =    106.849     ,  EFFC    =   4.23015     ,  EFFIN   =   3.15105     ,  TRO     =   437.101     ,
   TRI     =   400.652     ,  WCS2    =    6.89979     ,  QCS2    =   66.1826     ,  CEFFS2  =   1.50000     ,  TSP2    =   325.601     ,
   TCO2    =   315.140     ,  WA2     =    .160245E-03,  WPR2    =   .600817E-04,  QSHL2   =   1.63001     ,  QAF2    =   .253694E-01,
   QAA2    =   .634544E-01,   QBB2    =    .421551E-01,  CAB2    =   40.1516     ,  CBC2    =   8.81568     ,  QDD2    =   2.15524     ,
   QFF2    =   1.19649     ,  QTOT2   =    227.111     ,
 &END
 &OUTMGB
   QBRGTM  =   52.7526     ,  QSLTM   =    14.2397     ,  QGRTM   =   169.347     ,  QMGB    =   236.339     ,
 &END
 &OUTRGB
   QSLTR   =   48.4683     ,  QBRGTR  =    23.5637     ,  QGRTR   =   291.244     ,  QRGB    =   363.276     ,
 &END
 &OUTSUM
   QAFCT   =   .664619     ,  QTT     =    .983739     ,  QFSL    =   1467.14     ,  QLINTF  =   7366.74     ,  QFR     =   270.463     ,
   QGGSP   =   4.69693     ,  QASP    =    .0          ,  QGGSA   =   1.43898     ,  QASA    =   .0          ,
 &END
```

Table XXX. STJ346A Fuel and Lubricant Temperatures and Heat Loads at End of Loiter

```
                                   F L I G H T   P O I N T   N U M B E R   39

&OUTIN
  ABCD   =               , TT3    =  355.000      , TFTANK =  251.000  , EFGH   =            , HROTOR =  5800.00  ,
  TLIMO  =  575.000      , TLIMF  =  600.000      , POP    =  .450000  , QAFR   =  .0        , W33P   =  .290000  ,
  WS2P   =  .500000      , WRBP   =  .500000      , W39P   =  .570000  , WS1P   =  .500000   , WBBP   =  .500000  ,
  SRATIO =  .464000      , PA     =               , PT3    =  29.5000  , PT7    =  7.50000   ,
&END
&OUTSTM

  T      =  251.000      ,           251.000      ,           251.437  ,           250.637   ,           250.648   ,
            247.984      ,           258.653      ,           257.839  ,           256.271   ,           256.297   ,
            .0           ,           252.138      ,           252.139  ,           242.527   ,           257.624   ,
            260.889      ,           260.594      ,           292.438  ,           283.024   ,           .0        ,
            317.377      ,           317.144      ,           317.421  ,           317.421   ,           317.421   ,
            317.322      ,           317.421      ,           316.644  ,           276.865   ,           .0        ,
            276.823      ,           276.823      ,           275.050  ,           303.990   ,           298.789   ,
            298.789      ,           298.789      ,           276.823  ,           276.295   ,           321.834   ,
            276.323      ,           327.809      ,           327.569  ,           327.569   ,           320.133   ,
            319.630      ,           .0           ,           .0       ,           .0        ,           .0        ,
  QLIN   =  .0           ,           -1625.78     ,           -5404.01 ,           -1667.64  ,           -896.670  ,
            -317.931     ,           .0           ,           -437.394 ,           -1289.61  ,           -5457.82  ,
            -2374.45     ,           .0           ,           .0       ,           .0        ,           .0        ,
            -285.846     ,           .0           ,           -124.911 ,           -831.666  ,           .0        ,
            -50.8105     ,           .0           ,           -619.919 ,           .0        ,           -362.997  ,
            -84.3778     ,           -1639.48     ,           .0       ,           -209.765  ,           -617.319  ,
            .0           ,           .0           ,           .0       ,           .0        ,           .0        ,
            .0           ,           .0           ,           .0       ,           .0        ,           .0        ,
            .0           ,           .0           ,           .0       ,           .0        ,           .0        ,
            .0           ,           .0           ,           .0       ,           .0        ,           .0        ,
&END
&OUTBTH

  QAFO   =  .0           , GMFO   =  806.404      ,
&END
&OUTPL
  PMOP   =  69.5292      , DPOF   =  .411465      , DPAO   =  .0       , DPMO   =  1.98565   ,
&END
&OUTPF
  P3     =  110.160      , P1     =  6.30000      , DPRGB  =  2.32953  , DPHEX  =  1.53018   , DPMFO  =  .807446   ,
  DPAFO  =  .215000      , PDBP   =  103.860      , DPGGN  =  129.500  , DPAN   =  107.500   , PDGGP  =  130.307   ,
  PDAP   =  .215000      , EFFAP  =  .562499E-01, , EFFGP  =  .224211  , EFFBPH =  .486860   , EFFBPL =  .633362   ,
&END
&OUTFLW

  W      =  3580.00      ,           3580.00      ,           3580.00  ,           3580.00   ,           3580.00   ,
            3580.00      ,           3580.00      ,           3580.00  ,           1000.00   ,           1000.00   ,
            .0           ,           1000.00      ,           1000.00  ,           1000.00   ,           2580.00   ,
            2580.00      ,           2580.00      ,           2580.00  ,           2580.00   ,           .0        ,
            45.1182      ,           45.1182      ,           45.1182  ,           45.1182   ,           .0        ,
            45.1182      ,           .0           ,           45.1182  ,           45.1182   ,           .0        ,
            45.1182      ,           45.1182      ,           13.0843  ,           13.0843   ,           13.0343   ,
            13.0843      ,           13.0843      ,           32.0339  ,           25.7174   ,           25.7174   ,
```

Table XXX. STJ346A Fuel and Lubricant Temperatures and Heat Loads at End of Loiter (Continued)

```
            6.31654     ,            32.0339     ,            32.0339     ,            32.0339     ,            45.1182     ,
            45.1182     ,            45.1182     ,            .0          ,            .0          ,            .0          ,
  WBPL   =  3580.00     , WBPH    =  .0          ,
&END
&OUTLUB
  QOP    =  5.67957     , QOF     =  .504245E-01, QAC     =  .0          , QOT     =  -49.6005    , DTSP1   =  .680076E-03,
  DTSP2  =  .122248E-03, T21C    =  317.207     , CLINT   =  -5027.08    , QMOT    =  .241453     , QSP1    =  .991684E-02,
  QSP2   =  .719088E-03, QLUBE   =  801.759     ,
&END
&OUTFUL
  QBP    =  14.7959     , QHEX    =  .376494     , QGBT    =  .572265     , QAP     =  .248749     , QGGP    =  80.2815     ,
  DTAN   =  .0          , QFOT    =  .144027     , DTGGN   =  -9.41479    , SYSEFF  =  .224256E-01, QGGN    =  -2395.22    ,
  QAN    =  .0          ,
&END
&OUTHOR
  FPKPLB =  2.44321     , OPHP    =  1.33463     , ABPHP   =  .950924     , ATPHP   =  .190185     , FPHP    =  1.14111     ,
  GHP    =  220.000     , HPHP    =  150.000     , RMGBHP  =  379.034     , PO      =  13.2750     , PBC     =  6.63750     ,
&END
&OUTCN1
  WBB    =  12.8587     , QBBRG   =  286.047     , CEFFO   =  .889337     , CEFFIN  =  1.54088     , TROUT   =  319.780     ,
  TRIN   =  351.637     , WCS1    =  12.8587     , QCS1    =  60.3107     , CEFFS1  =  1.50000     , TSP1    =  29[illegible].759     ,
  TOD1   =  286.604     , WA1     =  .358177E-03, QSHL1   =  .358370     , QFF1    =  -1.24997    , QBF1    =  .181816     ,
  GPA1   =  -7.04208    , QSC1    =  3.00557     , QTOT1   =  526.599     , TSBBQ   =  11.4605     , TSRBQ   =  6.29824     ,
  QGEAR1 =  167.230     ,
&END
&OUTCN2
  WRB    =  6.54214     , GRB     =  97.3929     , EFFO    =  4.32955     , EFFIN   =  3.22047     , TRO     =  416.797     ,
  TRI    =  380.486     , WCS2    =  6.54214     , QCS2    =  64.8560     , CEFFS2  =  1.50000     , TSP2    =  307.752     ,
  TOD2   =  296.851     , WA2     =  .371443E-03, WPR2    =  .123814E-03, QSHL2   =  .421282     , QAF2    =  -.139821E-02,
  QAA2   =  .833173E-02, GBB2    =  .553507E-02, QAB2    =  5.27201     , GBC2    =  1.15752     , QDD2    =  .282988     ,
  QFF2   =  .157102     , QTOT2   =  169.552     ,
&END
&OUTMGB
  QBRGTM =  49.9908     , QSLTM   =  13.2996     , QGRTM   =  169.721     , QMGB    =  233.012     ,
&END
&OUTRGB
  QSLTR  =  45.2683     , QBRGTR  =  21.3076     , QGRTR   =  292.372     , GRGB    =  358.948     ,
&END
&OUTSUM
  QAFOT  =  .887379     , UTT     =  1.60367     , UFSL    =  1216.49     , QLINTF  =  -19471.3    , QFR     =  -79.6327    ,
  QGGSP  =  10.4072     , UASP    =  .0          , QGGSA   =  .796720     , QASA    =  .0          ,
&END
```

Table XXXI. STRJ334B Output Nomenclature in Order of Printout

Symbol	Description
Program Input	
&OUT-IN	Input Section
ABCD	Inlet Total Temperature, °R
TT3	Compressor Discharge Temperature, °R
TFTANK	Fuel Tank Temperature, °F
EFGH	Mission Time, min
HROTOR	Engine Speed, rpm
TLIMO	Temperature Limit of Oil, °F
TLIMF	Temperature Limit of Fuel, °F
POP	Percent of PT3 Outside of Seals
W33P	Percent of Pump Oil Flow to Bearing Compartment No. 2
WS2P	Percent of Pump Oil Flow to Bearing Compartment No. 2 Seals
WRBP	Percent of Pump Oil Flow to Roller Bearing
W39P	Percent of Pump Oil Flow to Bearing Compartment No. 1
WS1P	Percent of Pump Oil Flow to Bearing Compartment No. 1 Seals
WBBP	Percent of Pump Oil Flow to Ball Bearing
PT24	Compressor Inlet Pressure, psia
PA	Ambient (Altitude) Pressure, psia
PT3	Compressor Discharge Pressure, psia
PT7	Cold Turbine Discharge Pressure, psia
Output - Temperature and Heat (Reference figure 159.)	
&OUTSTM	Common System Temperatures and Heat
T(1), T(2), T(3), ...	System Temperatures per Schematic, °F
QLIN(1), QLIN(2), ...	System Line Segment Heat per Schematic, Btu/hr
Output - Heat Transfer	
&OUTBTH	Heat Loads to Fuel System, Btu/min
QAFR	Airframe Heat Exchanger Load
QMFO	Lubrication System Heat Exchanger Load
Output - Lubrication System Pressures	
&OUTPL	Output Lubrication System
DPOP	Oil Pump Pressure Rise, psi
DPOF	Oil Filter Pressure Drop, psi
DPFO	Fuel/Oil Cooler Pressure Drop, psi
NHM	Pump (and Hydromotor) Speed, rpm

Table XXXI. STRJ334B Output Nomenclature in Order of Printout (Continued)

Symbol	Description
Output - Fuel System Pressures	
&OUTPF	Output Fuel System
P1	Airframe Fuel Tank Pressure, psi
DPAF	Fuel/Air Cooler Pressure Drop, psi
DPHEX	Airframe Cooler Pressure Drop, psi
DPMFO	Fuel/Oil Cooler Pressure Drop, psi
PDBP	Boost Pump Pressure Rise, psi
DPGGN	Gas Generator Nozzle Pressure Drop, psi
DPRN	Ram Nozzle Pressure Drop, psi
DPDV	Diverter Valve Pressure Drop, psi
DPFP	Fuel Pump Pressure Rise, psi
EFLFP	Main Pump Low Flow Element Efficiency
EFHFP	Main Pump High Flow Element Efficiency
EFFBPH	Boost Pump High Flow Element Efficiency
EFFBPL	Boost Pump Low Flow Element Efficiency
EFHM	Hydromotor Efficiency
Output - Flowrates (Reference figure 159.)	
&OUTFLW	Output Flows
W(1), W(2), ...	System Flows { lb/hr for fuel lb/min for oil lb/sec for air
WBPL	Boost Pump Flow (Low)
WBPH	Boost Pump Flow (High)
Output - Lubrication System	
&OUTLUB	Output from Lubrication System
QOP	Main Oil Pump Heat Generation, Btu/min
QOF	Oil Filter Throttling Heat, Btu/min
QFOC	Fuel/Oil Cooler Throttling Heat, Btu/min
QOT	Oil Tank Heat Conduction, Btu/min
DTSP1	Bearing Compartment No. 1 Scavenge Pump Temperature Rise, °F
DTSP2	Bearing Compartment No. 2 Scavenge Pump Temperature Rise, °F
T30C	Back Calculated Oil Tank Temperature, °F
QLINT	Total Line Segment Heat, Btu/min
QSP1	Scavenge Pump No. 1 Heat, Btu/min
QSP2	Scavenge Pump No. 2 Heat, Btu/min
QLUBE	Total Lubrication System Heat, Btu/min

Table XXXI. STRJ334B Output Nomenclature in Order of Printout (Continued)

Symbol	Description
Output - Fuel System	
&OUTFUL	Output From Fuel System
QBP	Boost Pump Heat, Btu/min
QHEX	Airframe Fuel/Oil Cooler Throttling Heat, Btu/min
QHP	Hydromotor Heat Generation, Btu/min
QHFP	Main Pump High Flow Element Heat, Btu/min
QLFP	Main Pump Low Flow Element Heat, Btu/min
DTRB	Ram Manifold Temperature Rise, °F
QFO	Main Fuel/Oil Cooler Throttling Heat, Btu/min
DTMB	Gas Generator Manifold Temperature Rise, °F
QAFM	Fuel/Air Cooler Heat, Btu/min
QFAT	Fuel/Air Cooler Throttling Heat, Btu/min
Output - Front Bearing Compartment	
&OUTCN1	Output Bearing Compartment No. 1
TROUT	Outer Race Temperature, °F
TRIN	Inner Race Temperature, °F
TSPF1	Forward Seal Plate Temperature, °F
TSPR1	Aft Seal Plate Temperature, °F
QBBRG	Ball Bearing Heat Generation, Btu/min
QCSF1	Forward Carbon Seal Heat Generation, Btu/min
QCSR1	Aft Carbon Seal Heat Generation, Btu/min
WAF1	Air Leakage Forward Seal, lb/sec
WAR1	Air Leakage After Seal, lb/sec
QSHLF1	Forward Seal Leakage Heat, Btu/min
QSHLR1	Aft Seal Leakage Heat, Btu/min
QTOT1	Total Bearing Compartment No. 1 Heat, Btu/min
QCOND1	Total Conduction Bearing Compartment No. 1, Btu/min
Output - Rear Bearing Compartment	
&OUTCN2	Output Bearing Compartment No. 2
QRB	Roller Bearing Heat Generation, Btu/min
TRO	Outer Race Temperature, °F
TRI	Inner Race Temperature, °F
QCSF2	Forward Carbon Seal Heat Generation, Btu/min
QCSR2	Aft Carbon Seal Heat Generation, Btu/min
TSPF2	Forward Seal Plate Temperature, °F
TSPR2	Aft Seal Plate Temperature, °F
WAF2	Forward Seal Air Leakage, lb/sec
WAR2	Aft Seal Air Leakage, lb/sec
QSHLF2	Forward Seal Leakage Heat, Btu/min
QSHLR2	Aft Seal Leakage Heat, Btu/min
QTOT2	Total Bearing Compartment No. 2 Heat, Btu/min
QCOND2	Total Conduction Bearing Compartment No. 2, Btu/min

Table XXXI. STRJ334B Output Nomenclature in Order of Printout (Continued)

Symbol	Description
Output - Bearing Compartments	
&OCOMPT	Output Bearing Compartments
WCS1	Oil Flow to Carbon Seals Bearing Compartment No. 1, lb/min
WBB	Oil Flow to Ball Bearing, lb/min
PO	Pressure Outside Bearing Compartment, psia
PBC	Pressure Inside Bearing Compartment, psia
WCS2	Oil Flow to Carbon Seals Bearing Compartment No. 2, lb/min
WRB	Oil Flow to Roller Bearing, lb/min
Output - System Line Geometry	
&OUTLIN	System Line Description
LINLTH(1), ...	Line Segment Length, ft
LINDIA(1), ...	Line Segment Diameter, ft

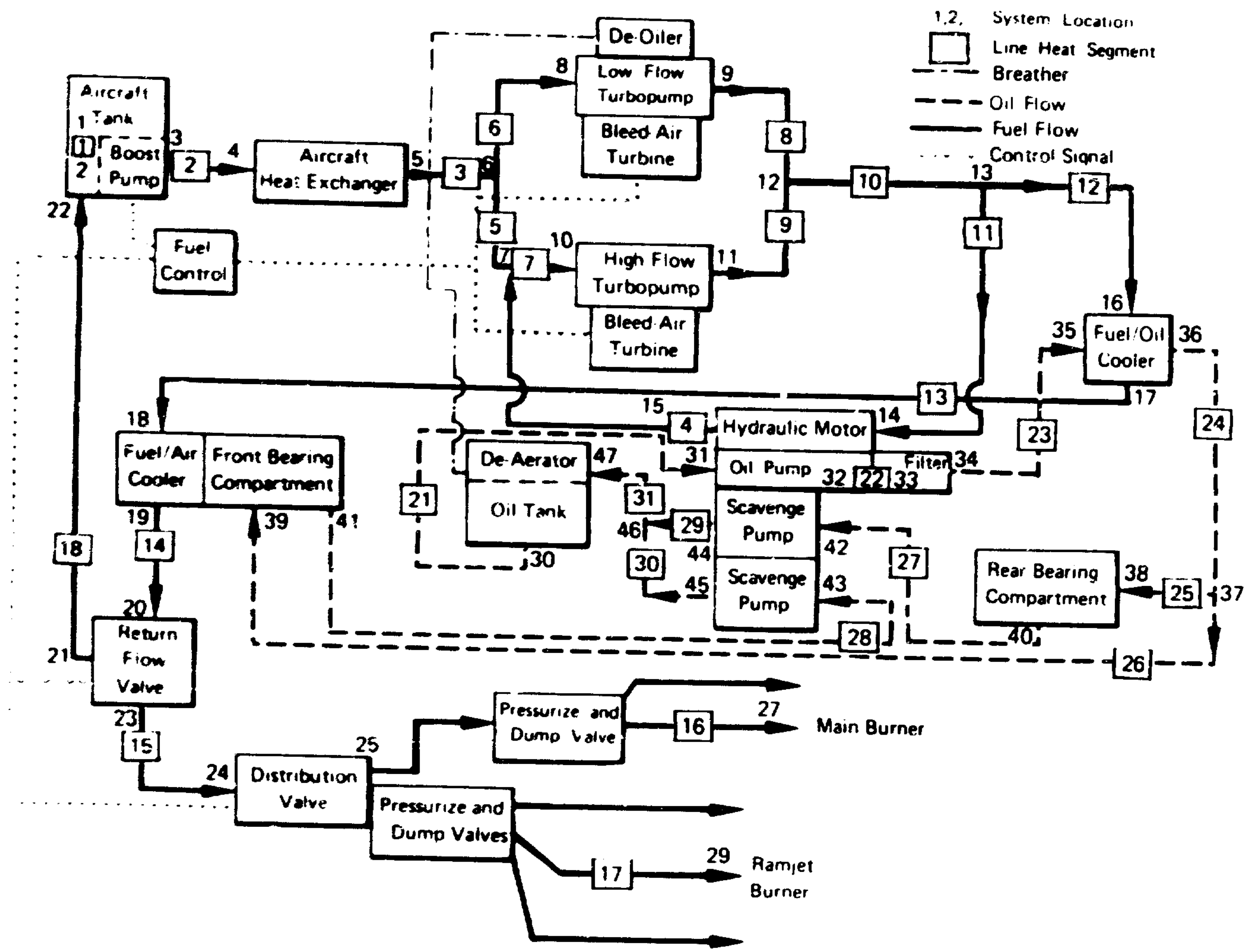


Figure 159. STRJ334B Engine Fuel and Lubrication Baseline Systems and Computer Program Designations

Table XXXII. STRJ334B Fuel and Lubricant Temperatures and Heat Loads at Takeoff

```
                                    F L I G H T   P O I N T   N U M B E R   1

&OUTIN
  ABCO   =              , TT3    =  741.000    , TFTANK =  110.000    , EFGH   =  .0         , HROTOR =  8360.00    ,
  TLIMO  =  575.000     , TLIMF  =  660.000    , PDP    =  .450000    , W33P   =  .400000    , WS2P   =  .500000    ,
  WRBP   =  .500000     , W39P   =  .600000    , WS1P   =  .500000    , WBBP   =  .500000    , PT24   =  14.7000    ,
  PA     =  14.7000     , PT3    =  176.350    , PT7    =  .0         ,
&END
&OUTSTM

  T      =  110.000     ,           110.000    ,           110.597    ,           110.530    ,           130.384    ,
            130.347     ,           130.752    ,           130.341    ,           132.080    ,           130.749    ,
            132.019     ,           132.094    ,           132.088    ,           132.065    ,           134.281    ,
            132.078     ,           136.559    ,           136.514    ,           136.537    ,           136.506    ,
            136.506     ,           135.787    ,           136.506    ,           136.489    ,           136.489    ,
            136.481     ,           136.406    ,           .0         ,           .0         ,           294.431    ,
            294.367     ,           294.550    ,           294.550    ,           294.552    ,           294.063    ,
            200.000     ,           199.907    ,           198.257    ,           198.798    ,           281.783    ,
            311.217     ,           278.379    ,           308.568    ,           278.379    ,           308.568    ,
            296.492     ,           296.038    ,           .0         ,           .0         ,           .0         ,
            .0          ,           .0         ,           .0         ,           .0         ,           .0         ,
            .0          ,                      ,           .0         ,           .0         ,           .0         ,
  QLIN   =  .0          ,           -1346.49   ,           -760.101   ,           -71.8925   ,           -38.5870   ,
            -44.8946    ,           -38.0398   ,           -57.0333   ,           -29.9435   ,           -141.353   ,
            -32.3625    ,           -211.298   ,           -955.951   ,           -527.522   ,           -363.834   ,
            .0          ,           .0         ,           -347.875   ,           -1603.03   ,           .0         ,
            -61.1983    ,           .0         ,           -468.826   ,           35.7973    ,           -609.776   ,
            -614.944    ,           -1304.85   ,           -1542.97   ,           .0         ,           .0         ,
            -438.530    ,           .0         ,           .0         ,           .0         ,           .0         ,
            .0          ,           .0         ,           .0         ,           .0         ,           .0         ,
            .0          ,           .0         ,           .0         ,           .0         ,           .0         ,
            .0          ,           .0         ,           .0         ,           .0         ,           .0         ,
&END
&OUTBTH

  QAFR   =  6700.00     , QMFO   =  1479.76    ,
&END
&OUTPL
  DPOP   =  46.2571     , DPOF   =  .271762    , DPFO   =  1.30832    , NHM    =  2089.76    ,
&END
&OUTPF
  P1     =  19.7000     , DPAF   =  2.24655    , DPHEX  =  27.5000    , DPMFO  =  27.5000    , PDBP   =  127.500    ,
  DPGGM  =  276.350     , DPRN   =  114.700    , DPDV   =  161.650    , DPFP   =  306.096    , EFLFP  =  .585489    ,
  EFMFP  =  .659207     , EFFBPH =  .586118    , EFFBPL =  .661396    , EFHM   =  .525369    ,
&END
&OUTFLW

  W      =  43342.0     ,           43342.0    ,           43342.0    ,           43342.0    ,           43342.0    ,
            43342.0     ,           28342.0    ,           15000.0    ,           15000.0    ,           31342.0    ,
            31342.0     ,           46342.0    ,           46342.0    ,           3000.00    ,           3000.00    ,
            43342.0     ,           43342.0    ,           43342.0    ,           43342.0    ,           43342.0    ,
            1000.00     ,           1000.00    ,           42342.0    ,           42342.0    ,           42342.0    ,
            42342.0     ,           42342.0    ,           .0         ,           .0         ,           35.8011    ,
```

Table XXXII. STRJ334B Fuel and Lubricant Temperatures and Heat Loads at Takeoff (Continued)

```
             35.8011     ,             35.8011     ,            35.8011     ,            35.8011     ,            35.8011     ,
             35.8011     ,             35.8011     ,            14.3204     ,            21.4807     ,            14.3204     ,
             21.4807     ,             14.3204     ,            21.4807     ,            14.3204     ,            21.4807     ,
             35.8011     ,             35.8011     ,            .0          ,            .0          ,            .0          ,
             .0          ,             .0          ,            .0          ,            .0          ,            .0          ,
             .0          ,             .0          ,            .0          ,            .0          ,            .0          ,
  WBPL   =   30000.0     ,  WBPH   =   13342.0     ,
&END
&OUTLUB
   QOP   =   2.93130     ,  QOF    =   .258148E-01,  QFOC   =  .122073     ,  QOT    =  -32.6431    ,  DTSP1  =  .124657E-03,
  DTSP2  =   .788252E-04,  T30C   =   294.007     ,  QLINT  =  -118.091    ,  QSP1   =  .120693E-02,  QSP2   =  .502956E-03,
  QLUBE  =   1473.07     ,  QGENL  =   1591.16     ,
&END
&OUTFUL
   QOP   =   200.385     ,  QHEX   =   75.6176     ,  QHP    =  53.2618     ,  QHFP   =  318.187     ,  QLFP   =  208.496     ,
   DTMB  =   -.821381E-01,  QFO    =   76.5228     ,  DTRB   =  .0          ,  QAFM   =  .0          ,  QFAT   =  6.26678     ,
   QOV   =   .0          ,  QLINTF =   -110.650    ,  QGENF  =  938.737     ,  QTOTF  =  7527.88     ,
&END
&OUTCN1
  TROUT  =   306.084     ,  TRIN   =   389.401     ,  TSPF1  =  267.456     ,  TSPR1  =  292.250     ,  QBBRG  =  710.853     ,
  QCSF1  =   108.096     ,  QCSR1  =   147.131     ,  WAF1   =  .156786E-02,  WAR1   =  .182916E-02,  QSHLF1 =  11.4987     ,
  QSHLR1 =   13.4152     ,  QTOT1  =   1064.38     ,  QCOND1 =  73.3868     ,  TC1    =  58.7000     ,
&END
&OUTCN2
   QRB   =   168.893     ,  TRO    =   420.777     ,  TRI    =  365.470     ,  QCSF2  =  147.156     ,  QCSR2  =  147.156     ,
  TSPF2  =   338.493     ,  TSPR2  =   338.493     ,  WAF2   =  .182916E-02,  WAR2   =  .182916E-02,  QSHLF2 =  12.5584     ,
  QSHLR2 =   12.5584     ,  QTOT2  =   523.705     ,  QCOND2    15.3823     ,  TC2    =  58.7000     ,
&END
&OCOMPT
   WCS1  =   10.7403     ,  WBB    =   10.7403     ,  PO     =  79.3575     ,  PBC    =  39.6787     ,  WCS2   =  7.16022     ,
   WRB   =   7.16022     ,
&END
&OUTLIN

  LINLTH =   .0          ,             9.00000     ,            3.67000     ,            2.16700     ,            .330000     ,
             .670000     ,             .330000     ,            .831000     ,            .250000     ,            .831000     ,
             1.00000     ,             1.33000     ,            5.67000     ,            3.13000     ,            2.16000     ,
             3.06000     ,             1.27000     ,            2.00000     ,            10.8330     ,            .0          ,
             .167000     ,             .0          ,            1.00000     ,            .330000     ,            5.48000     ,
             5.42000     ,             7.20000     ,            7.40000     ,            .0          ,            .0          ,
             2.00000     ,             .0          ,            .0          ,            .0          ,            .0          ,
             .0          ,             .0          ,            .0          ,            .0          ,            .0          ,
             .0          ,             .0          ,            .0          ,            .0          ,            .0          ,
             .0          ,             .0          ,            .0          ,            .0          ,            .0          ,
  LINDIA =   .0          ,             .0          ,            .0          ,            .0          ,            .0          ,
             .830000E-01,              .250000     ,            .250000     ,            .410000E-01,            .142000     ,
             .410000E-01,              .142000     ,            .830000E-01,            .142000     ,            .200000     ,
             .420000E-01,              .167000     ,            .187000     ,            .187000     ,            .187000     ,
             .142000     ,             .920000E-01,             .330000     ,            .458300E-01,            .0          ,
             .750000E-01,              .0          ,            .187000     ,            .187000     ,            .750000E-01,
             .830000E-01,              .750000E-01,             .750000E-01,            .0          ,            .0          ,
             .0          ,             .0          ,            .0          ,            .0          ,            .0          ,
             .0          ,             .0          ,            .0          ,            .0          ,            .0          ,
             .0          ,             .0          ,            .0          ,            .0          ,            .0          ,
&END                                                                                                   .0          ,
&OUTCON

   TAMB  =                ,  NOIL   =                3,  NFUEL  =               3,
&END
```

Table XXXIII. STRJ334B Fuel and Lubricant Temperatures and Heat Loads [illegible] Cruise Out

```
                                    F L I G H T   P O I N T   N U M B E R   15

&OUTIN
  ABCD    =               ,  TT3     =              ,  TFTANK =  114.000    ,  EFGH  =               ,  HROTOR =  137.000    ,
  TLIMO   =   575.000     ,  TLIMF   =   600.000    ,  POP    =  .450000    ,  W33P  =   .400000     ,  WS2P   =  .500000    ,
  WRBP    =   .500000     ,  W39P    =   .600000    ,  WS1P   =  .500000    ,  WBBP  =   .500000     ,  PT24   =  75.1000    ,
  PA      =               ,  PT3     =   75.1000    ,  PT7    =  .0         ,
&END
&OUTSTM

  T       =   114.000     ,              114.000    ,            114.537    ,            118.[illegible]8 ,         167.217    ,
              168.841     ,              171.792    ,            168.952    ,            169.876     ,            172.064    ,
              172.899     ,              170.910    ,            171.161    ,            171.549     ,            172.700    ,
              171.602     ,              179.745    ,            131.590    ,            227.347     ,            228.270    ,
              228.270     ,              239.919    ,            228.270    ,            228.945     ,            228.945    ,
              .0          ,              .0         ,            234.743    ,            286.393     ,            261.565    ,
              261.861     ,              262.096    ,            262.096    ,            262.098     ,            264.357    ,
              200.000     ,              200.764    ,            214.244    ,            209.815     ,            237.196    ,
              235.873     ,              254.400    ,            247.844    ,            254.400     ,            247.844    ,
              250.466     ,              252.610    ,            .0         ,            .0          ,            .0         ,
              .0          ,              .0         ,            .0         ,            .0          ,            .0         ,
              .0          ,                         ,            691.187    ,            .0          ,            .0         ,
  QLIN    =   .0          ,              35465.5    ,            14055.7    ,            1283.66     ,            679.114    ,
              845.507     ,              705.319    ,            1047.90    ,            533.972     ,            2569.56    ,
              592.722     ,              3836.15    ,            16261.4    ,            8685.36     ,            5983.60    ,
              .0          ,              .0         ,            6412.46    ,            .0          ,            530810.    ,
              323.399     ,              .0         ,            2466.56    ,            808.171     ,            5705.81    ,
              5747.06     ,              7403.11    ,            7722.09    ,            .0          ,            .0         ,
              2319.95     ,              .0         ,            .0         ,            .0          ,            .0         ,
              .0          ,              .0         ,            .0         ,            .0          ,            .0         ,
              .0          ,              .0         ,            .0         ,            .0          ,            .0         ,
              .0          ,              .0         ,            .0         ,            .0          ,            .0         ,
&END
&OUTBTH

  QAFR    =   6700.00     ,  QMFO    =   1151.32    ,
&END
&OUTPL
  DPOP    =   58.4030     ,  DPOF    =   .346255    ,  DPFO   =  1.67165    ,  NHM   =   2316.71     ,
&END
&OUTPF
  P1      =   5.41000     ,  DPAF    =   .429240    ,  DPHEX  =  27.5000    ,  DPMFO =   27.5000     ,  PDBP   =  127.500    ,
  DPGGN   =   175.100     ,  DPRN    =   175.100    ,  DPDV   =  .0         ,  DPFP  =   203.029     ,  EFLFP  =  .629936    ,
  EFHFP   =   .652749     ,  EFFBPH  =   .558437    ,  EFFBPL =  .659425    ,  EFHM  =   .576930     ,
&END
&OUTFLW

  W       =   17100.0     ,              17100.0    ,            17100.0    ,            17100.0     ,            17100.0    ,
              17100.0     ,              2100.00    ,            15000.0    ,            15000.0     ,            5100.00    ,
              5100.00     ,              20100.0    ,            20100.0    ,            3000.00     ,            3000.00    ,
              17100.0     ,              17100.0    ,            17100.0    ,            17100.0     ,            17100.0    ,
              1000.00     ,              1000.00    ,            16100.0    ,            16100.0     ,            .0         ,
              .0          ,              .0         ,            16100.0    ,            16100.0     ,            40.9833    ,
```

Table XXXIII. STRJ334B Fuel and Lubricant Temperatures and Heat Loads at the End of Cruise Out (Continued)

```
            40.9833     ,           40.9833     ,           40.9833     ,           40.9833     ,           40.9833     ,
            40.9833     ,           40.9833     ,           16.3933     ,           24.5900     ,           16.3933     ,
            24.5900     ,           16.3933     ,           24.5900     ,           16.3933     ,           24.5900     ,
            40.9833     ,           40.9833     ,           .0          ,           .0          ,           .0          ,
            .0          ,           .0          ,           .0          ,           .0          ,           .0          ,
            .0          ,           34.1000     ,           .0          ,           .0          ,           .0          ,
 WBPL   =   17100.0     , WBPH   =  .0          ,
&END
&OUTLUB
 QOP    =   4.28921     , QOF    =  .351480E-01, QFOC   =   .182149     , QOT    =  165.650     , DTSP1  =  .117516E-03,
 DTSP2  =   .746476E-04, T30C   =  261.785     , GLINT  =   707.252     , GSP1   =  .127026E-02, GSP2   =  .539494E-03,
 GLUBE  =   1153.95     , QGENL  =  446.699     ,
&END
&OUTFUL
 QBP    =   71.5752     , QHEX   =  29.9728     , QHP    =   29.3187     , QHFP   =  36.1684     , QLFP   =  117.264     ,
 DTMB   =   .0          , GFO    =  30.8686     , DTRB   =   57.4471     , QAFM   =  6736.98     , QFAT   =  .484569     ,
 QDV    =   .0            GLINTF =  10496.1     , GGENF  =   315.652     , QTOTF  =  24248.8     ,
&END
&OUTCN1
 TROUT  =   217.890     , TRIN   =  211.496     , TSPF1  =   210.547     , TSPR1  =  210.812     , QBBRG  =  5.30872     ,
 QCSF1  =   1.12605     , QCSR1  =  1.60489     , WAF1   =   .528483E-03, WAR1   =  .616563E-03, QSHLF1 =  10.8824     ,
 QSHLR1 =   12.6961     , QTOT1  =  278.459     , QCOND1 =   246.441     , TC1    =  792.015     ,
&END
&OUTCN2
 QRB    =   2.11823     , TRO    =  225.016     , TR1    =   221.861     , QCSF2  =  1.80507     , QCSR2  =  1.80507     ,
 TSPF2  =   215.736     , TSPR2  =  215.736     , WAF2   =   .616563E-03, WAR2   =  .616563E-03, QSHLF2 =  12.6476     ,
 QSHLR2 =   12.6476     , QTOT2  =  163.729     , QCOND2 =   132.705     , TC2    =  792.015     ,
&END
&OCOMPT
 WCS1   =   12.2950     , WBB    =  12.2950     , PO     =   33.7950     , PBC    =  16.8975     , WCS2   =  8.19667     ,
 WRB    =   8.19667     ,
&END
&OUTLIN

 LINLTH =   .0          ,           9.00000     ,           3.67000     ,           2.16700     ,           .330000     ,
            .670000     ,           .330000     ,           .831000     ,           .250000     ,           .831000     ,
            1.00000     ,           1.33000     ,           5.67000     ,           3.13000     ,           2.16000     ,
            3.06000     ,           1.27000     ,           2.00000     ,           10.8330     ,           .0          ,
            .167000     ,           .0          ,           1.00000     ,           .330000     ,           5.48000     ,
            5.42000     ,           7.20000     ,           7.40000     ,           .0          ,           .0          ,
            2.00000     ,           .0          ,           .0          ,           .0          ,           .0          ,
            .0          ,           .0          ,           .0          ,           .0          ,           .0          ,
            .0          ,           .0          ,           .0          ,           .0          ,           .0          ,
            .0          ,           .0          ,           .0          ,           .0          ,           .0          ,
 LINDIA =   .0          ,           .250000     ,           .250000     ,           .410000E-01,           .142000     ,
            .830000E-01,           .142000     ,           .830000E-01,           .142000     ,           .200000     ,
            .410000E-01,           .187000     ,           .187000     ,           .187000     ,           .187000     ,
            .920000E-01,           .920000E-01,           .330000     ,           .458300E-01,           .0          ,
            .142000     ,           .0          ,           .187000     ,           .187000     ,           .750000E-01,
            .750000E-01,           .750000E-01,           .750000E-01,           .0          ,           .0          ,
            .830000E-01,           .0          ,           .0          ,           .0          ,           .0          ,
            .0          ,           .0          ,           .0          ,           .0          ,           .0          ,
            .0          ,           .0          ,           .0          ,           .0          ,           .0          ,
            .0          ,           .0          ,           .0          ,           .0          ,           .0          ,
&END
&OUTCON

 TAMB   =               , NOIL   =            3, NFUEL  =             3,
&END
```

Table XXXIV. STRJ334B Fuel and Lubricant Temperatures and Heat Loads at Start of Cruise Back

```
                                      F L I G H T   P O I N T   N U M B E R   20

&OUTIN
  ABCD   =               , TT3    =               , TFTANK =  115.000   , EFGH   =               , HROTOR =  130.000   ,
  TLIMC  =  575.000      , TLIMF  =  600.000      , PCP    =  .450000   , W33P   =  .400000      , WS2P   =  .500000   ,
  WRBP   =  .500000      , W39P   =  .600000      , WS1P   =  .500000   , WBBP   =  .500000      , PT24   =  68.0000   ,
  PA     =               , PT3    =  73.0200      , PT7    =  .0        ,
&END
&OUTSTM

  T      =  115.000      ,           115.000      ,           115.537   ,           120.254      ,           171.581   ,
            173.299      ,           176.976      ,           173.409   ,           174.316      ,           177.316   ,
            178.141      ,           175.408      ,           175.672   ,           176.056      ,           177.185   ,
            176.138      ,           184.736      ,           186.687   ,           230.524      ,           231.504   ,
            231.504      ,           243.123      ,           231.504   ,           232.224      ,           232.224   ,
            .0           ,           .0           ,           238.402   ,           292.953      ,           261.124   ,
            261.420      ,           261.656      ,           261.656   ,           261.658      ,           263.915   ,
            200.000      ,           200.763      ,           214.217   ,           209.797      ,           236.584   ,
            235.584      ,           253.766      ,           247.536   ,           253.766      ,           247.536   ,
            250.028      ,           252.168      ,           .0        ,           .0           ,           .0        ,
            .0           ,           .0           ,           .0        ,           .0           ,           .0        ,
            .0           ,                        ,           654.024   ,           .0           ,           .0        ,
  QLIN   =  .0           ,           35378.2      ,           13999.4   ,           1280.61      ,           639.179   ,
            843.477      ,           697.970      ,           1045.42   ,           528.401      ,           2561.24   ,
            591.279      ,           3822.68      ,           16199.9   ,           8663.36      ,           5967.47   ,
            .0           ,           .0           ,           6423.20   ,           .0           ,           526174.   ,
            323.794      ,           .0           ,           2469.54   ,           809.143      ,           5711.54   ,
            5752.61      ,           7412.53      ,           7730.74   ,           .0           ,           .0        ,
            2322.80      ,           .0           ,           .0        ,           .0           ,           .0        ,
            .0           ,           .0           ,           .0        ,           .0           ,           .0        ,
            .0           ,           .0           ,           .0        ,           .0           ,           .0        ,
            .0           ,           .0           ,           .0        ,           .0           ,           .0        ,
&END
&OUTSTH

  GAFR   =  6700.00      , GMFD   =  1146.55      ,
&END
&OUTPL
  DPOP   =  58.7023      , DPOF   =  .348033      , DPFC   =  1.68027   , NHM    =  2321.75      ,
&END
&OUTPF
  P1     =  5.37000      , DPAF   =  .381232      , DPHEX  =  27.5000   , DPMFC  =  27.5000      , PDBP   =  127.500   ,
  DPGGN  =  173.020      , DPRN   =  166.000      , DPDV   =  5.02000   , DPFP   =  200.901      , EFLFP  =  .630985   ,
  EFMFP  =  .651860      , EFFBPH =  .557790      , EFFBPL =  .559379   , EFHM   =  .578279      ,
&END
&OUTFLW

  W      =  16000.0      ,           16000.0      ,           16000.0   ,           16000.0      ,           16000.0   ,
            16000.0      ,           1000.00      ,           15000.0   ,           15000.0      ,           4000.00   ,
            4000.00      ,           19000.0      ,           19000.0   ,           3000.00      ,           3000.00   ,
            16000.0      ,           16000.0      ,           16000.0   ,           16000.0      ,           16000.0   ,
            1000.00      ,           1000.00      ,           15000.0   ,           15000.0      ,           .0        ,
            .0           ,           .0           ,           15000.0   ,           15000.0      ,           41.1005   ,
```

Table XXXIV. STRJ334B Fuel and Lubricant Temperatures and Heat Loads at Start of Cruise Back (Continued)

```
             41.1005    ,            41.1005    ,            41.1005    ,            41.1005    ,            41.1005    ,
             41.1005    ,            41.1005    ,            16.4402    ,            24.6603    ,            16.4402    ,
             24.6603    ,            16.4402    ,            24.6603    ,            16.4402    ,            24.6603    ,
             41.1005    ,            41.1005    ,            .0         ,            .0         ,            .0         ,
             .0         ,            .0         ,            .0         ,            .0         ,            .0         ,
             .0         ,            29.4000    ,            .0         ,            .0         ,            .0         ,
 WBPL    =   16000.0    , WBPH    =  .0         ,
&END
&OUTLUB
 QOP     =   4.32027    , QOF     =  .384243E-01, QFOC    =  .183486    , QOT     =  165.848    , DTSP1   =  .117902E-03,
 DTSP2   =   .746416E-04, T30C    =  261.330    , QLINT   =  708.060    , QSP1    =  .127790E-02, QSP2    =  .542289E-03,
 QLUBE   =   1148.93    , QGENL   =  440.671    ,
&END
&OUTFUL
 QBP     =   67.0215    , QHEX    =  28.0646    , QHP     =  28.9255    , QHFP    =  28.2645    , QLFP    =  115.807    ,
 DTMB    =   .0         , GFO     =  28.9575    , DTRB    =  60.7293    , QAFM    =  6082.37    , QFAT    =  .403863    ,
 QDV     =   5.11915    , QLINTF  =  10413.6    , QGENF   =  302.563    , QTOTF   =  23498.5    ,
&END
&OUTCN1
 TROUT   =   210.613    , TRIN    =  211.386    , TSPF1   =  210.485    , TSPR1   =  210.733    , QBBRG   =  5.03278    ,
 QCSF1   =   1.24961    , QCSR1   =  1.70086    , WAF1    =  .513712E-03, WAR1    =  .599330E-03, QSHLF1  =  10.5881    ,
 QSHLR1  =   12.3528    , QTOT1   =  276.338    , QCOND1  =  245.414    , TC1     =  759.510    ,
&END
&OUTCN2
 QRB     =   2.00998    , TRO     =  224.646    , TRI     =  221.609    , QCSF2   =  1.70102    , QCSR2   =  1.70102    ,
 TSPF2   =   215.619    , TSPR2   =  215.619    , WAF2    =  .599330E-03, WAR2    =  .599330E-03, QSHLF2  =  12.3060    ,
 QSHLR2  =   12.3060    , QTOT2   =  159.989    , QCOND2  =  129.965    , TC2     =  759.510    ,
&END
&OCOMPT
 WCS1    =   12.3301    , WBB     =  12.3301    , PO      =  32.8590    , PBC     =  16.4295    , WCS2    =  8.22010    ,
 WRB     =   8.22010    ,
&END
&OUTLIN

 LINLTH  =   .0         ,            9.00000    ,            3.67000    ,            2.16700    ,            .330000    ,
             .670000    ,            .330000    ,            .831000    ,            .250000    ,            .831000    ,
             1.00000    ,            1.33000    ,            5.67000    ,            3.13000    ,            2.16000    ,
             3.06000    ,            1.27000    ,            2.00000    ,            10.8330    ,            .0         ,
             .167000    ,            .0         ,            1.00000    ,            .330000    ,            5.48000    ,
             5.42000    ,            7.20000    ,            7.40000    ,            .0         ,            .0         ,
             2.00000    ,            .0         ,            .0         ,            .0         ,            .0         ,
             .0         ,            .0         ,            .0         ,            .0         ,            .0         ,
             .0         ,            .0         ,            .0         ,            .0         ,            .0         ,
             .0         ,            .0         ,            .0         ,            .0         ,            .0         ,
 LINDIA  =   .0         ,            .250000    ,            .250000    ,            .410000E-01,            .142000    ,
             .830000E-01,            .142000    ,            .830000E-01,            .142000    ,            .200000    ,
             .410000E-01,            .187000    ,            .187000    ,            .187000    ,            .187000    ,
             .920000E-01,            .920000E-01,            .330000    ,            .458300E-01,            .0         ,
             .142000    ,            .0         ,            .187000    ,            .187000    ,            .750000E-01,
             .750000E-01,            .750000E-01,            .750000E-01,            .0         ,            .0         ,
             .830000E-01,            .0         ,            .0         ,            .0         ,            .0         ,
             .0         ,            .0         ,            .0         ,            .0         ,            .0         ,
             .0         ,            .0         ,            .0         ,            .0         ,            .0         ,
             .0         ,            .0         ,            .0         ,            .0         ,            .0         ,
&END
&OUTCON

 TAMB    =              , NOIL    =          3. , NFUEL   =          3. ,
&END
```

Table XXXV. STRJ334B Fuel and Lubricant Temperatures and Heat Loads at the Initial Descent

```
                                     F L I G H T   P C I N T   N U M B E R   22

&OUTIN
  ABCD   =              , TT3    =            , TFTANK =  127.000   , EFGH   =            , HROTOR =  125.000   ,
  TLIMO  =  575.000     , TLIMF  =  600.000   , POP    =  .450000   , W33P   =  .400000   , WS2P   =  .500300   ,
  WRBP   =  .500000     , W39P   =  .600000   , WS1P   =  .500000   , WBBP   =  .500000   , PT24   =  56.2200   ,
  PA     =              , PT3    =  56.2200   , PT7    =  .0        ,
&END
&OUTSTR

  T      =  127.000     ,           127.000   ,           127.445   ,           149.672   ,           149.680   ,
            158.439     ,           167.C61   ,           159.040   ,           159.713   ,           167.509   ,
            168.230     ,           164.801   ,           165.641   ,           166.039   ,           166.830   ,
            168.092     ,           214.640   ,           224.384   ,           407.965   ,           411.644   ,
            411.644     ,           420.956   ,           411.644   ,           415.397   ,           415.397   ,
            .0          ,           .0        ,           425.819   ,           514.566   ,           258.549   ,
            258.636     ,           259.094   ,           259.094   ,           259.096   ,           261.289   ,
            200.000     ,           200.740   ,           213.753   ,           209.472   ,           234.658   ,
            233.784     ,           251.300   ,           245.355   ,           251.300   ,           245.355   ,
            247.733     ,           249.806   ,           .0        ,           .0        ,           .0        ,
            .0          ,           .0        ,           .0        ,           .0        ,           .0        ,
            .0          ,                     ,           720.125   ,           .0        ,           .0        ,
  QLIN   =  .0          ,           30973.6   ,           12618.3   ,           1305.47   ,           378.356   ,
            646.838     ,           702.668   ,           1049.48   ,           532.010   ,           2507.36   ,
            602.543     ,           3613.80   ,           15066.1   ,           7311.19   ,           4922.86   ,
            .0          ,           .0        ,           6365.83   ,           .0        ,           138141.   ,
            329.015     ,           .0        ,           2511.46   ,           823.532   ,           5794.09   ,
            5632.11     ,           7524.65   ,           7844.52   ,           .0        ,           .0        ,
            2357.57     ,           .0        ,           .0        ,           .0        ,           .0        ,
            .0          ,           .0        ,           .0        ,           .0        ,           .0        ,
            .0          ,           .0        ,           .0        ,           .0        ,           .0        ,
            .0          ,           .C        ,           .0        ,           .0        ,           .0        ,
&END
&OUTBTH

  QAFR   =  .0          , QMFC   =  1152.56   ,
&END
&OUTPL
  DPOP   =  63.9942     , DPOF   =  .379179   , DPFC   =  1.83078   , NHM    =  2422.22   ,
&END
&OUTPF
  P1     =  5.31000     , DPAF   =  .170000   , DPHEX  =  1.02611   , DPMFU  =  1.02611   , PDBP   =  101.026   ,
  DPGGN  =  156.220     , DPRN   =  156.220   , DPUV   =  .0        , DPFP   =  157.416   , EFLFP  =  .646540   ,
  EFHFP  =  .626781     , EFFBPH =  .513968   , EFFBPL =  .646351   , EFHM   =  .607175   ,
&END
&OUTFLW

  W      =  2919.00     ,           2919.00   ,           2919.00   ,           2919.00   ,           2919.00   ,
            2919.00     ,           100.000   ,           2819.00   ,           2819.00   ,           3100.00   ,
            3100.00     ,           5919.00   ,           5919.00   ,           3000.00   ,           3000.00   ,
            2919.00     ,           2919.00   ,           2919.00   ,           2919.00   ,           2919.00   ,
            1000.00     ,           1000.00   ,           1919.00   ,           1919.00   ,           .0        ,
            .C          ,           .0        ,           1919.00   ,           1919.00   ,           43.1114   ,
```

Table XXXV. STRJ334B Fuel and Lubricant Temperatures and Heat Loads at the Initial Descent (Continued)

```
             43.1114     ,             43.1114     ,             43.1114     ,             43.1114     ,             43.1114     ,
             43.1114     ,             43.1114     ,             17.2446     ,             25.8668     ,             17.2446     ,
             25.8666     ,             17.2446     ,             25.8668     ,             17.2446     ,             25.8668     ,
             43.1114     ,             43.1114     ,             .0          ,             .0          ,             .0          ,
             .0          ,             .0          ,             .0          ,             .0          ,             .0          ,
             .0          ,             25.[illegible] ,          .0          ,             .0          ,             .0          ,
 WBPL    =   2919.00     , WBPH    =   .0          ,
&END
&OUTLUB
 GOP     =   4.91663     , GOF     =   .436999E-01, QFOC    =   .208785     , QOT     =   168.099     , DTSP1   =   .125030E-03,
 DTSP2   =   .769324E-04, T30C    =   258.669     , CLINT   =   718.381     , QSP1    =   .142008E-02, QSP2    =   .599254E-03,
 CLUBE   =   1153.46     , QGENL   =   435.084     ,
&END
&OUTFUL
 QBP     =   10.3299     , QHEX    =   .194197     , QHP     =   19.9928     , QHFP    =   18.8678     , QLFP    =   15.8122     ,
 DTMB    =   .0          , QFO     =   .196224     , DTRE    =   99.1692     , QAFM    =   4691.39     , CFAT    =   .335806E-01,
 GDV     =   .0          , QLINTF  =   3782.29     , QGENF   =   65.4266     , QTOTF   =   8739.10     ,
&END
&OUTCN1
 TROUT   =   210.403     , TRIN    =   210.928     , TSPF1   =   210.067     , TSPR1   =   210.282     , QBBRG   =   4.83789     ,
 QCSF1   =   1.13412     , QCSR1   =   1.54366     , WAF1    =   .394084E-03, WAR1    =   .459765E-03, QSHLF1  =   8.22638     ,
 QSHLR1  =   9.59744     , QTOT1   =   273.145     , QCOND1  =   247.806     , TC1     =   792.591     ,
&END
&OUTCN2
 CRB     =   1.93266     , TRO     =   223.480     , TRI     =   220.645     , QCSF2   =   1.54379     , QCSR2   =   1.54379     ,
 TSPF2   =   214.966     , TSPR2   =   214.966     , WAF2    =   .459765E-03, WAR2    =   .459765E-03, QSHLF2  =   9.56284     ,
 QSHLR2  =   9.56284     , QTOT2   =   156.768     , QCOND2  =   132.622     , TC2     =   792.591     ,
&END
&OCOMPT
 WCS1    =   12.9334     , WBB     =   12.9334     , PO      =   25.2990     , PBC     =   12.6495     , WCS2    =   8.62228     ,
 WRB     =   8.62228     ,
&END
&OUTLIN

  LINLTH =   .0          ,             9.00000     ,             3.67000     ,             2.16700     ,             .330000     ,
             .670000     ,             .330000     ,             .831000     ,             .250000     ,             .831000     ,
             1.00000     ,             1.33000     ,             5.67000     ,             3.13000     ,             2.16000     ,
             3.06000     ,             1.27000     ,             2.00000     ,             10.8330     ,             .0          ,
             .167000     ,             .0          ,             1.00000     ,             .330000     ,             5.48000     ,
             5.42000     ,             7.20000     ,             7.40000     ,             .0          ,             .0          ,
             2.00000     ,             .0          ,             .0          ,             .0          ,             .0          ,
             .0          ,             .0          ,             .0          ,             .0          ,             .0          ,
             .0          ,             .0          ,             .0          ,             .0          ,             .0          ,
             .0          ,             .0          ,             .0          ,             .0          ,             .0          ,
  LINDIA =   .0          ,             .250000     ,             .250000     ,             .410000E-01,             .0          ,
             .830000E-01,             .142000     ,             .830000E-01,             .142000     ,             .142000     ,
             .410000E-01,             .167000     ,             .187000     ,             .187000     ,             .200000     ,
             .920000E-01,             .920000E-01,             .330000     ,             .458300E-01,             .187000     ,
             .142000     ,             .0          ,             .187000     ,             .187000     ,             .0          ,
             .750000E-01,             .750000E-01,             .750000E-01,             .0          ,             .750000E-01,
             .830000E-01,             .0          ,             .0          ,             .0          ,             .0          ,
             .0          ,             .0          ,             .0          ,             .0          ,             .0          ,
             .0          ,             .0          ,             .0          ,             .0          ,             .0          ,
             .0          ,             .0          ,             .0          ,             .0          ,             .0          ,
&END
&OUTLCN

  TAMB   =               , NOIL    =             3., NFUEL   =             3.,
&END
```

APPENDIX II

STJ346A FUEL AND LUBRICANT COMPONENT PERFORMANCE AND THERMAL CHARACTERISTICS

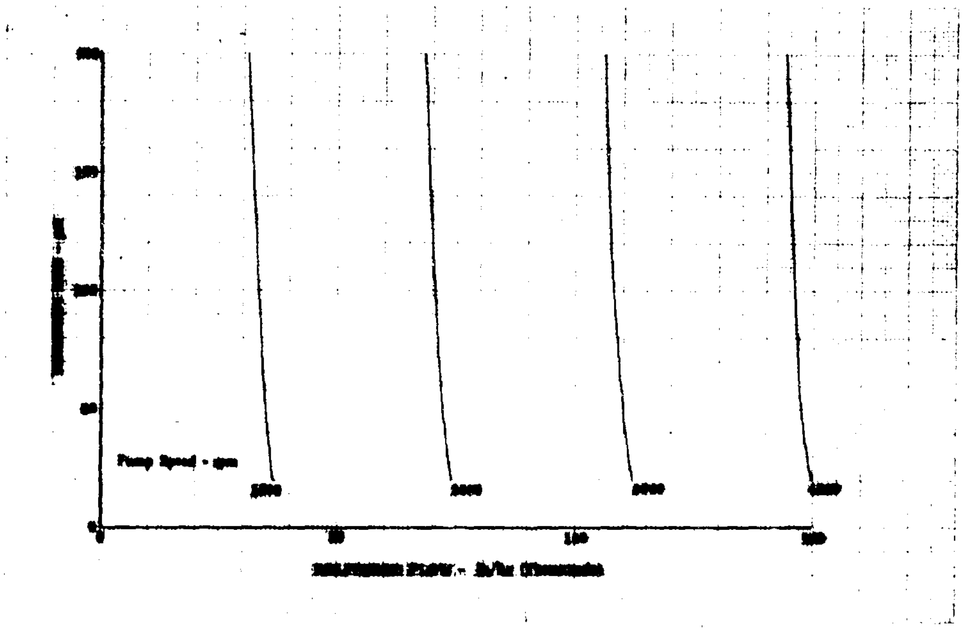


Figure 160. STJ346A High Flow Airframe Boost Pump Flow Map

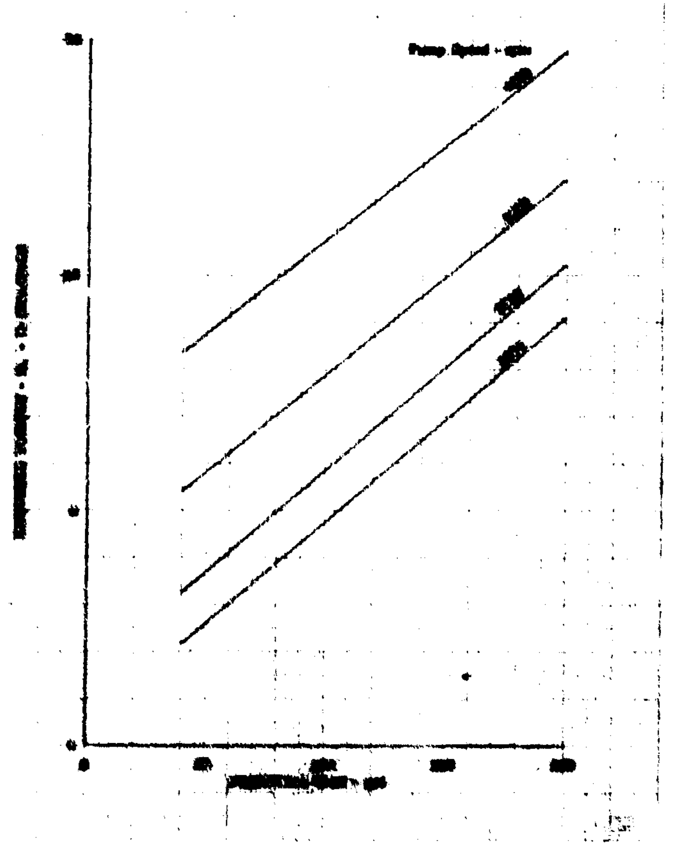


Figure 161. STJ346A High Flow Airframe Boost Pump Torque Characteristics

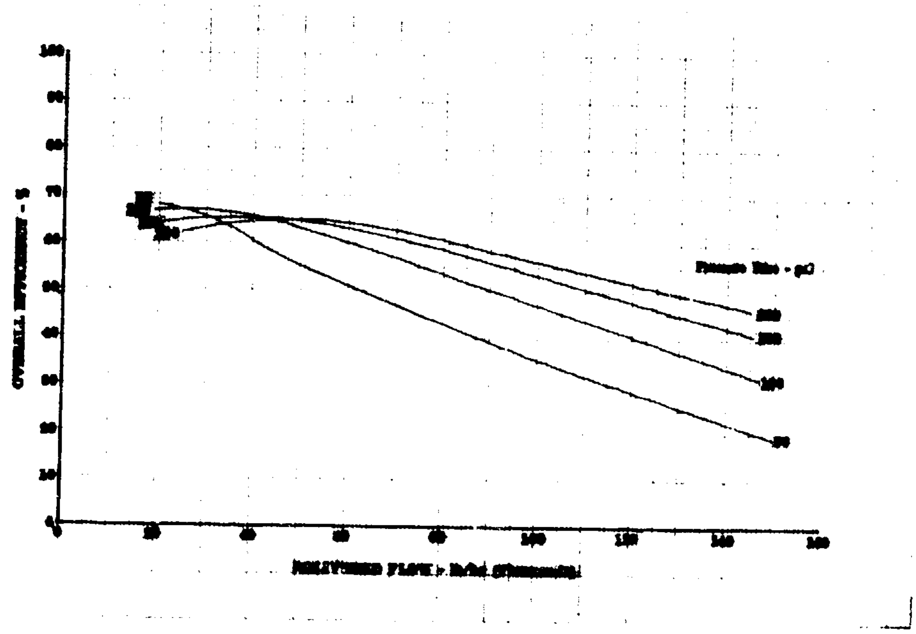


Figure 162. STJ346A High Flow Airframe Boost Pump Efficiency

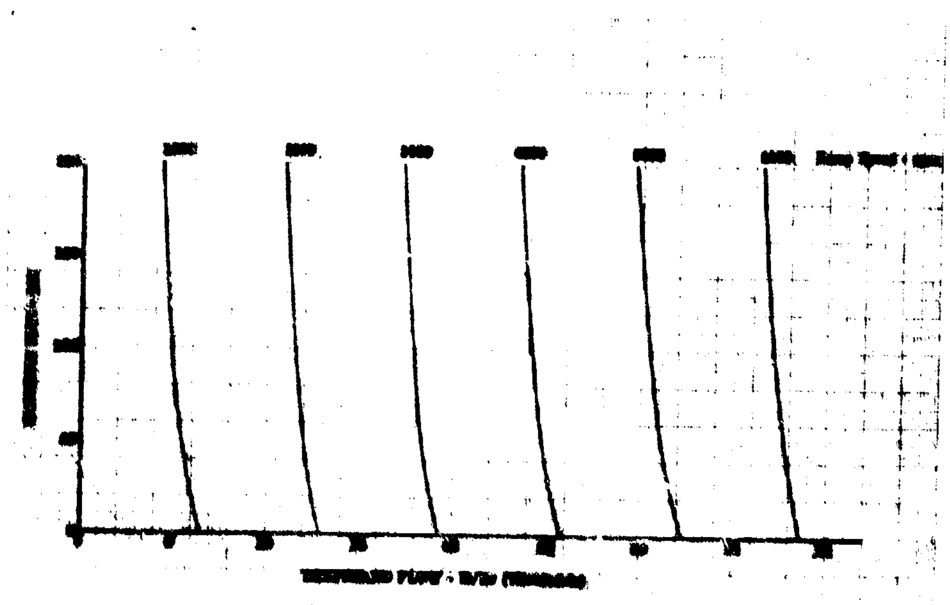


Figure 163. STJ346A Low Flow Airframe Boost Pump Flow Map

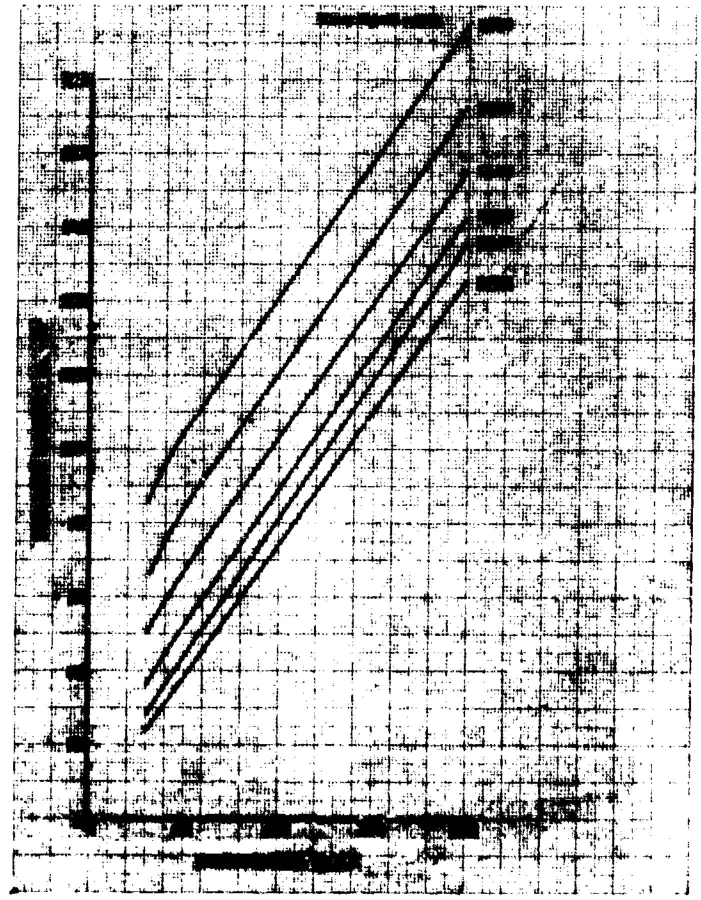


Figure 164. STJ346A Low Flow Airframe Boost Pump Torque Requirements

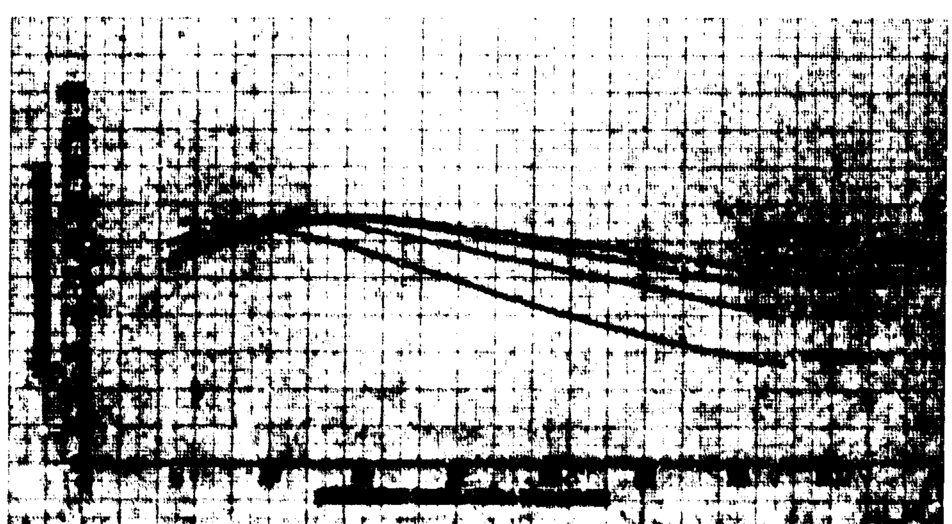


Figure 165. STJ346A Low Flow Airframe Boost Pump Efficiency Characteristics

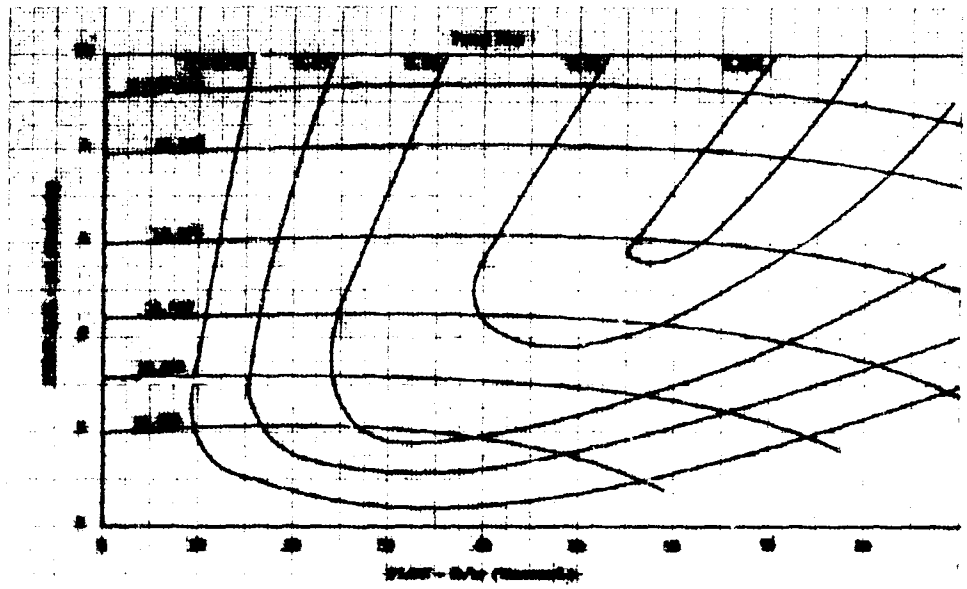


Figure 166. STJ346A Afterburner Turbopump Flow Map

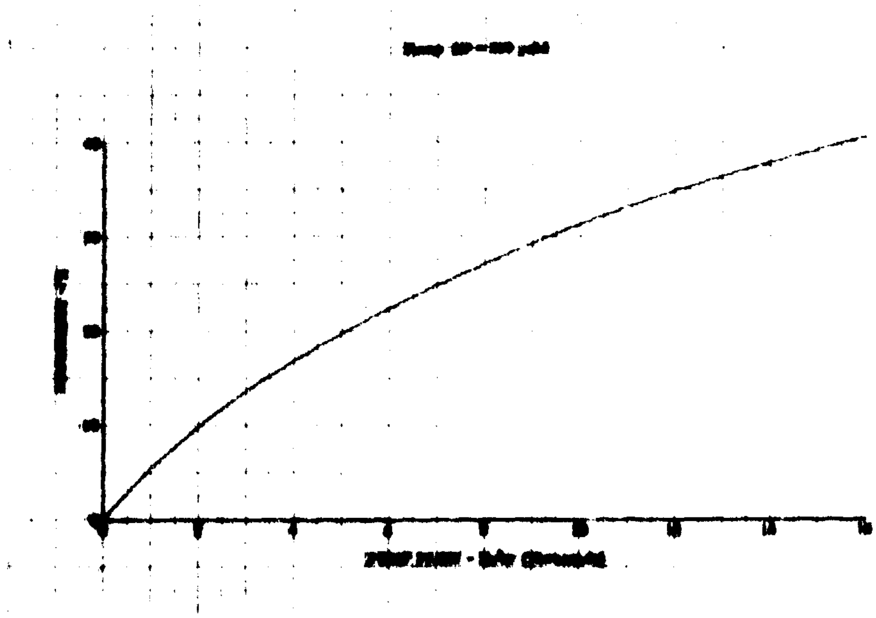


Figure 167. STJ346A Augmentor Pump Efficiency Requirements Nonaugmented Conditions

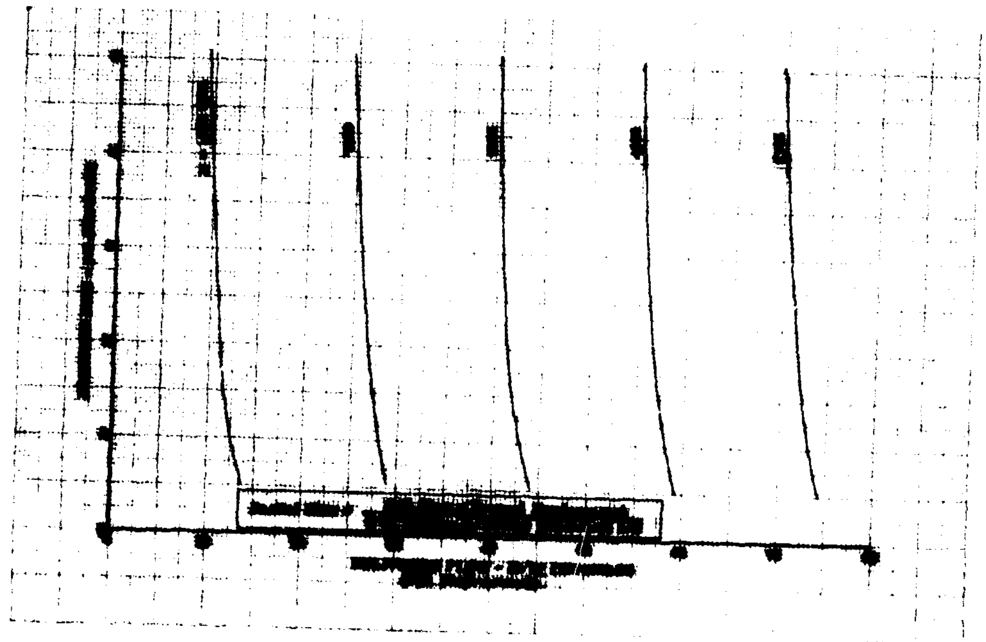


Figure 168. STJ346A Variable Displacement Gas Generator Vane Pump Full Displacement Flow Map

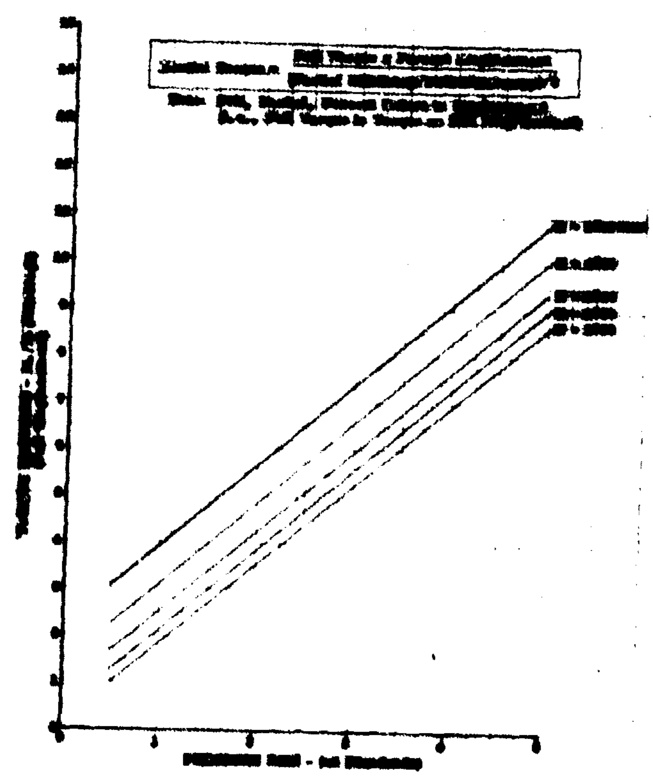


Figure 169. STJ346A Variable Displacement Gas Generator Vane Pump Full Displacement Torque Requirements

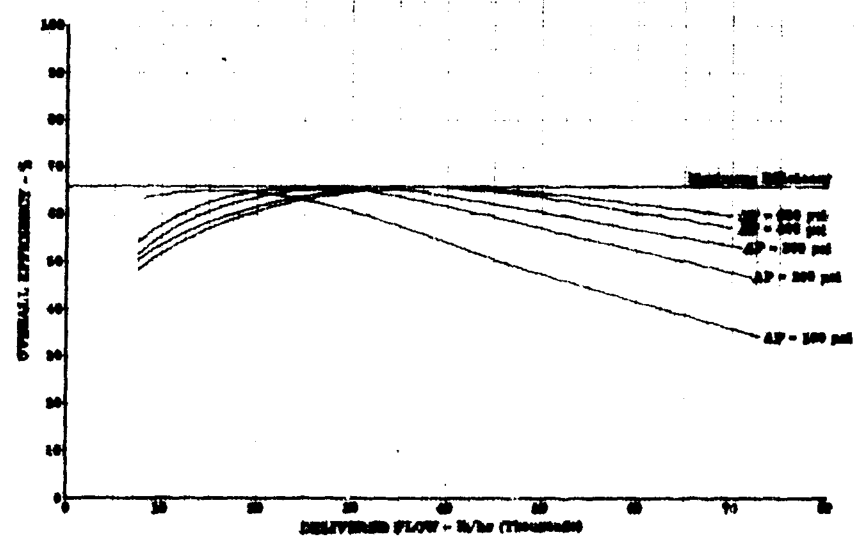


Figure 170. STJ346A Variable Displacement Gas Generator Vane Pump Full Displacement Efficiency Characteristics

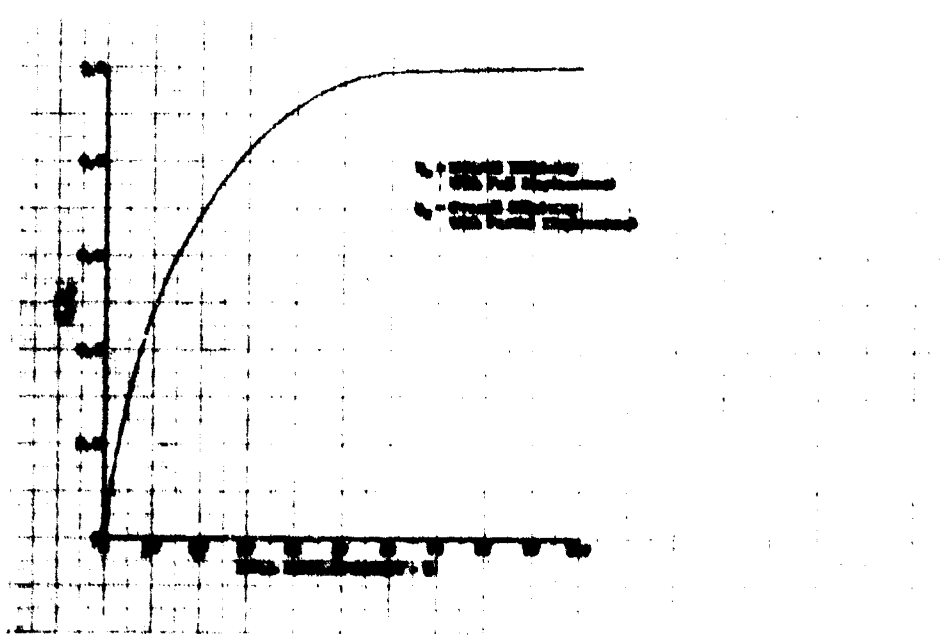


Figure 171. Overall Efficiency Correction for Partial Displacement Vane Pump Operation

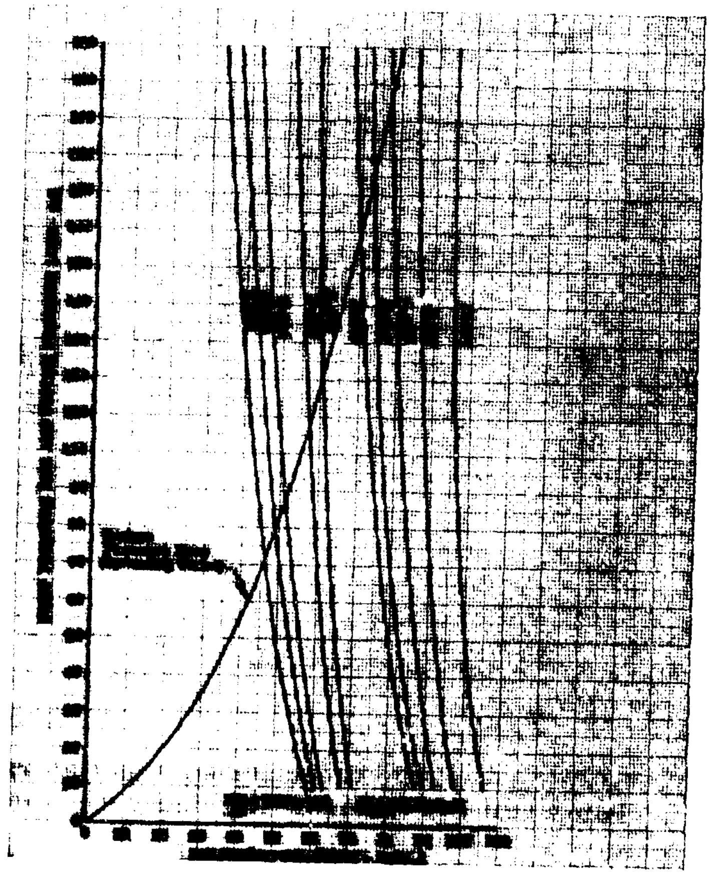


Figure 172. STJ346A Oil Pump Flow Map

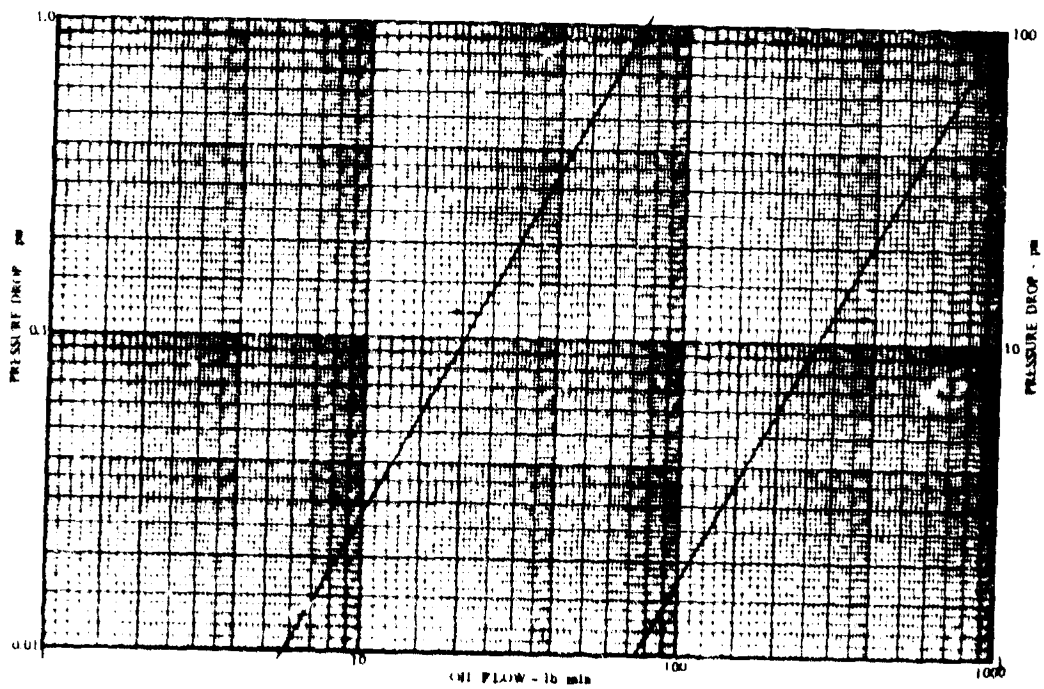


Figure 173. STJ346A Oil Filter Pressure Drop

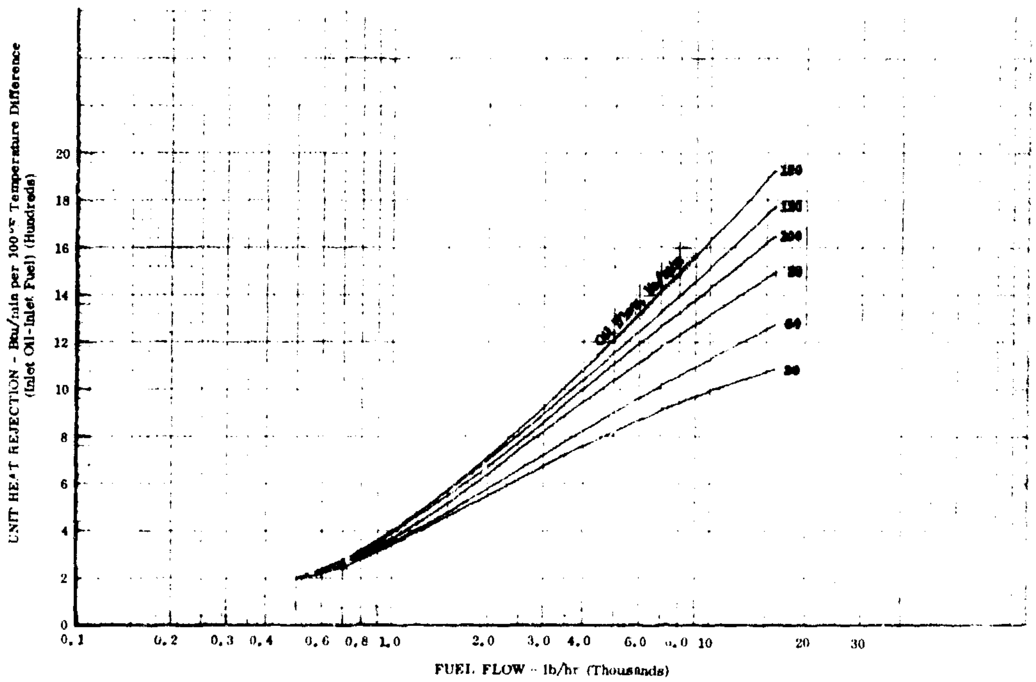


Figure 174. Unit Heat Rejection of STJ346A Auxiliary Fuel/Oil Cooler

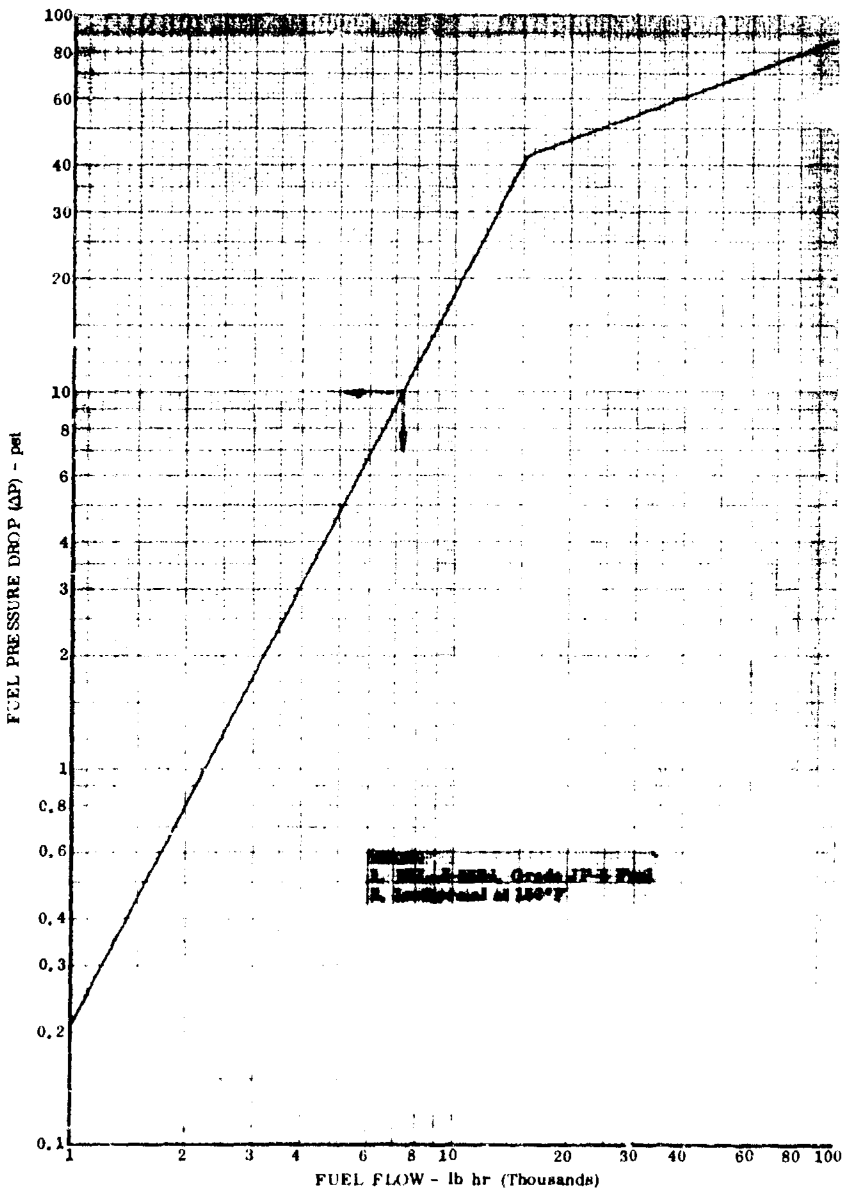


Figure 175. STJ346A Auxiliary Fuel/Oil Cooler - Fuel Side

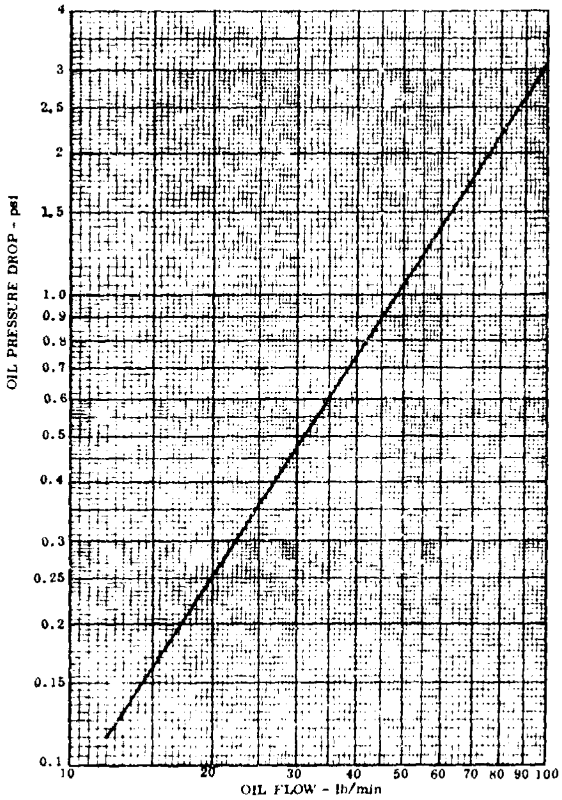


Figure 176. STJ346A Auxiliary Fuel/Oil Cooler - Oil Side

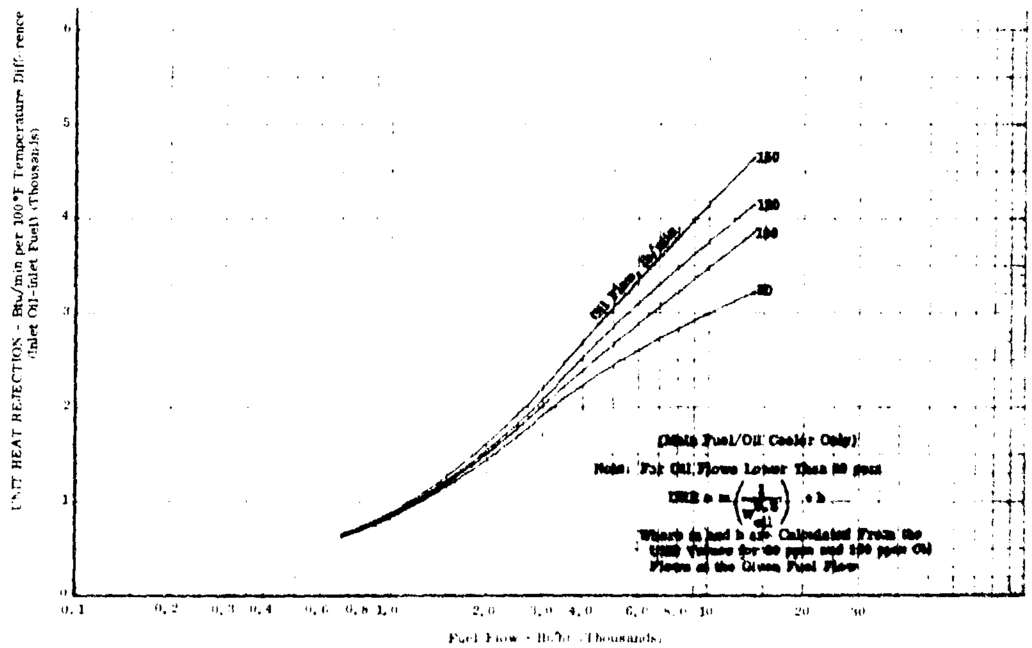


Figure 177. Unit Heat Rejection of STJ346A Airframe Heat Exchanger and Main Fuel/Oil Cooler

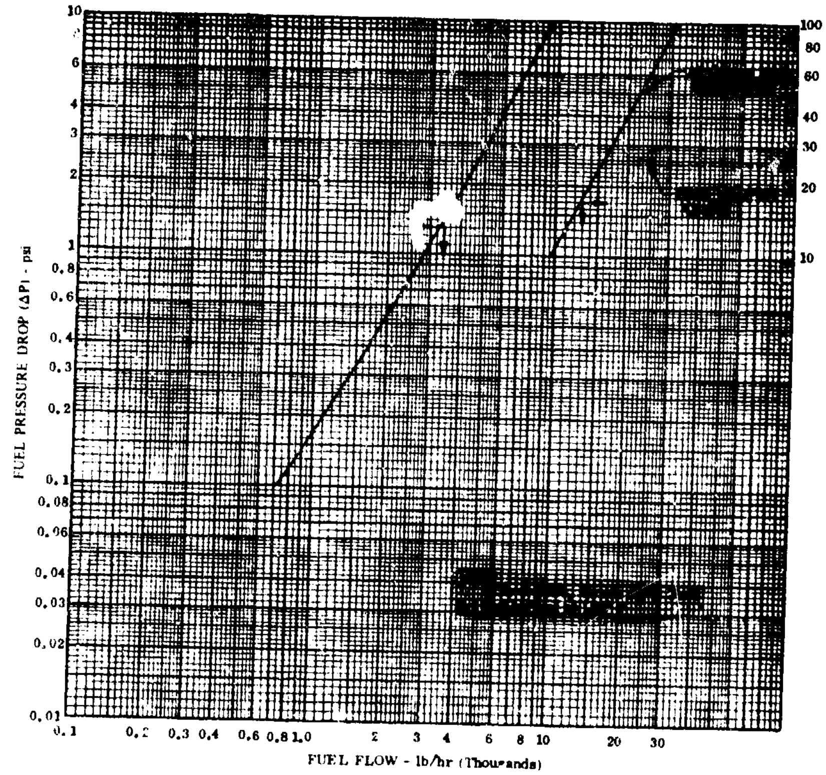


Figure 178. Fuel Side Pressure Drop for STJ346A Airframe Heat Exchanger and Main Fuel/Oil Cooler

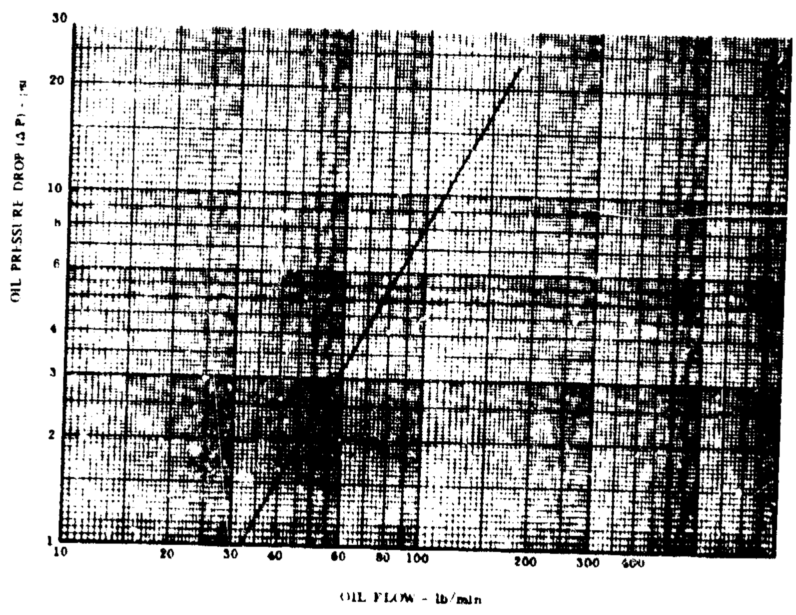


Figure 179. Oil Side Pressure Drop of STJ346A Fuel/Oil Cooler

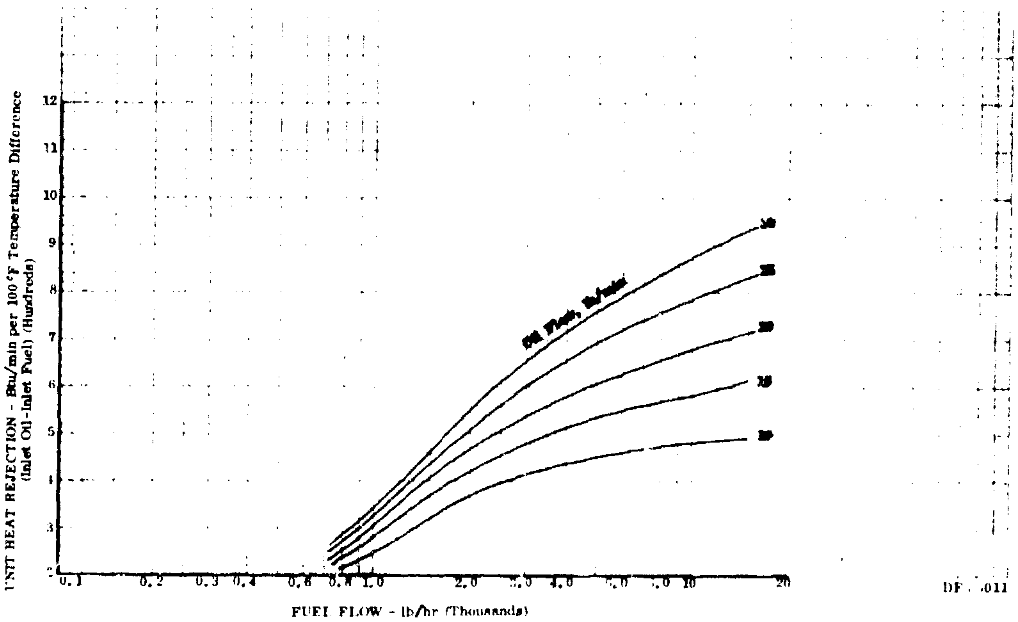


Figure 180. Unit Heat Rejection of STJ346A Remote Gearbox Fuel/Oil Cooler

APPENDIX III

STRJ334B FUEL AND LUBRICANT COMPONENT PERFORMANCE AND THERMAL CHARACTERISTICS

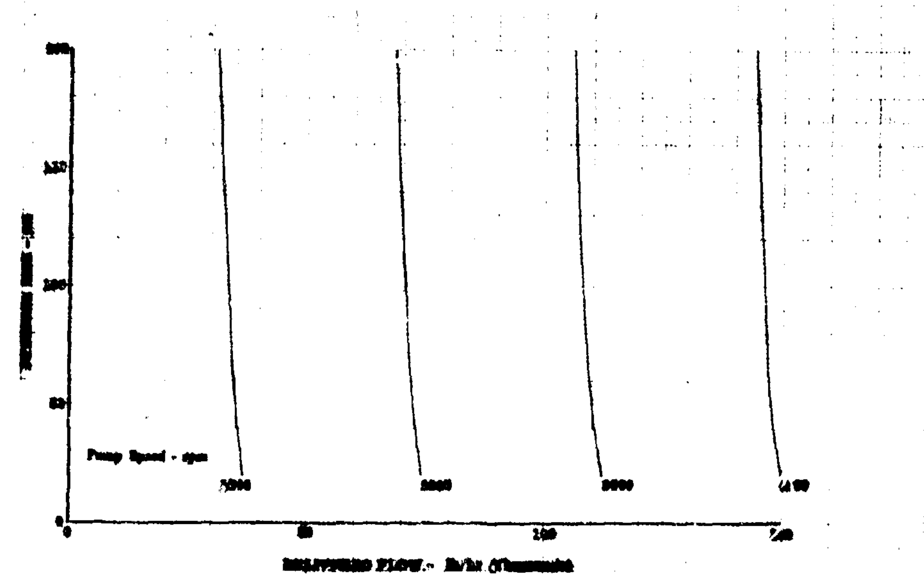


Figure 181. STRJ334B High Flow Airframe Boost Pump Flow Map

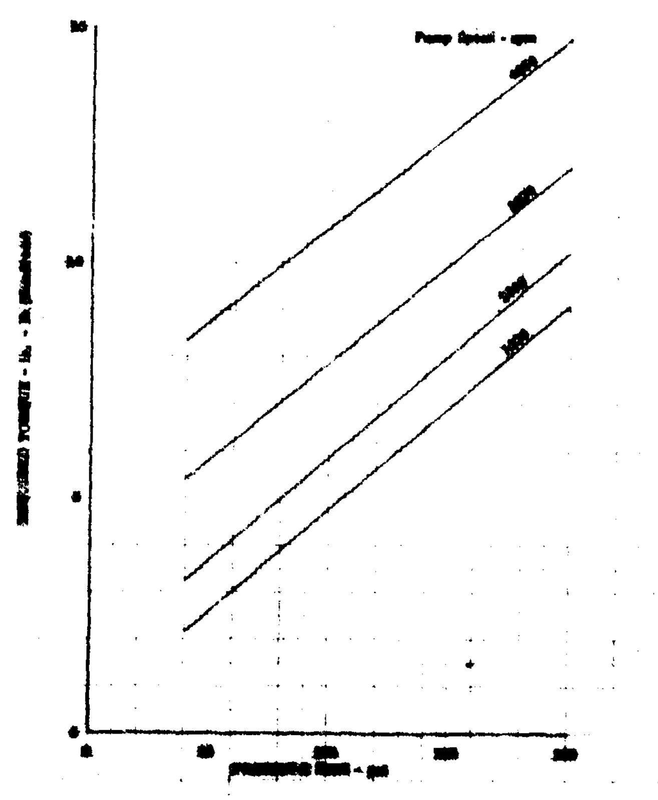


Figure 182. STRJ334B High Flow Airframe Boost Pump Torque Characteristics

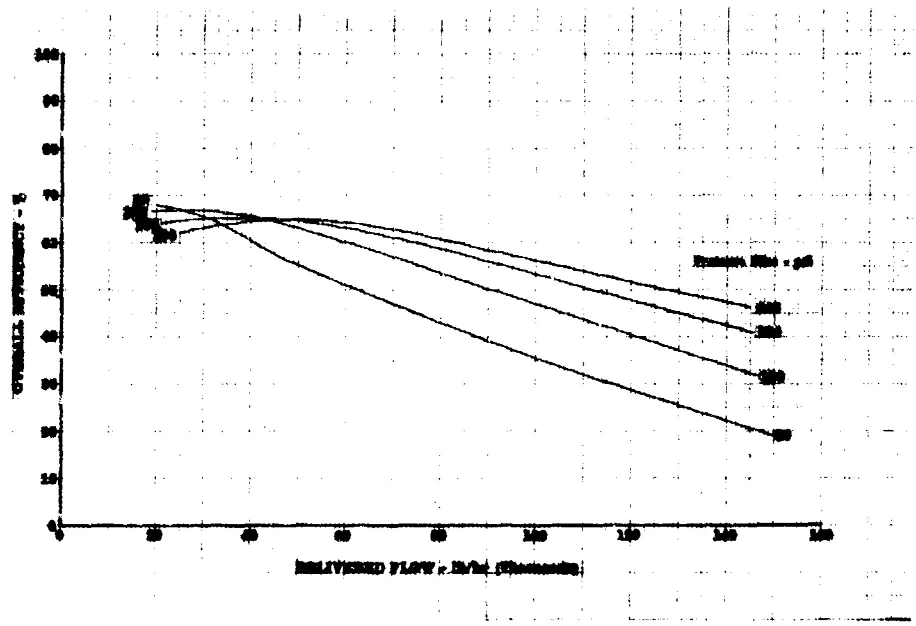


Figure 183. STRJ334B High Flow Airframe Boost Pump Efficiency Characteristics

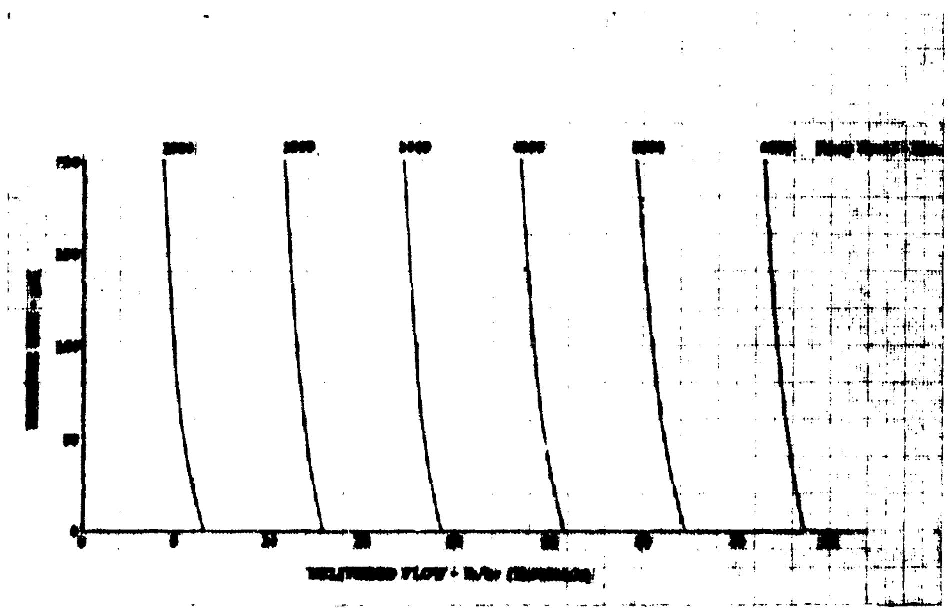


Figure 184. STRJ334B Low Flow Airframe Boost Pump Flow Map

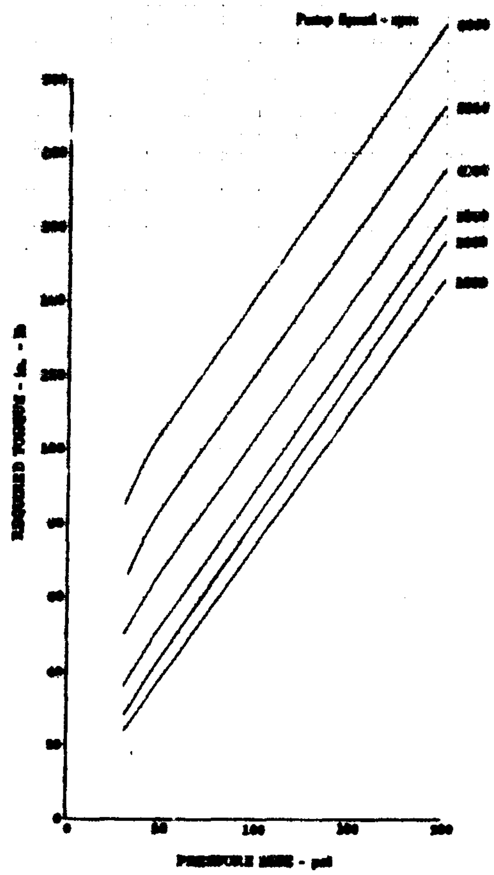


Figure 185. STRJ334B Low Flow Airframe Boost Pump Torque Requirements

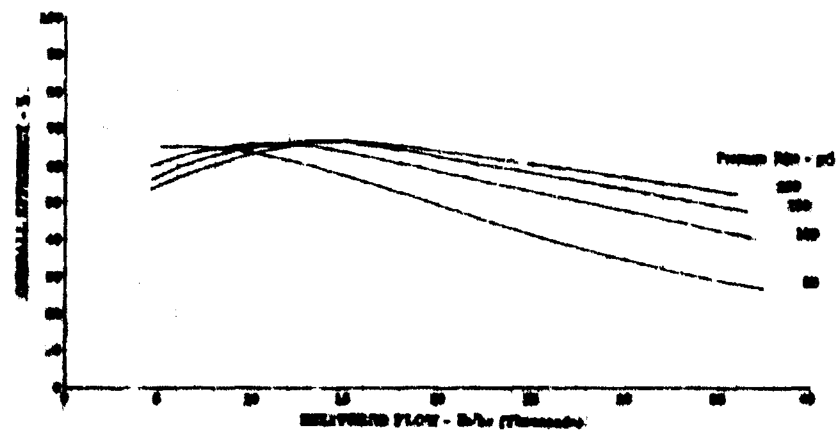


Figure 186. STRJ334B Low Flow Airframe Boost Pump Efficiency Characteristics

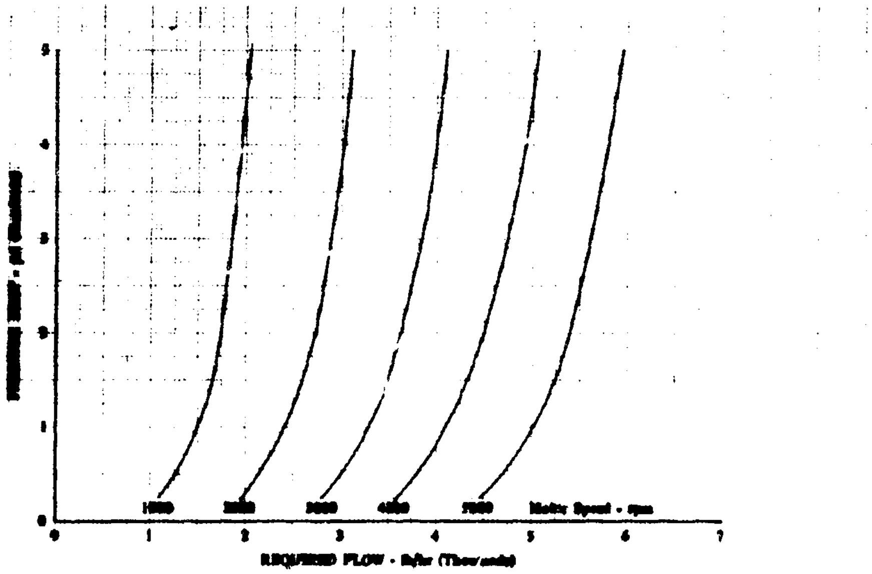


Figure 187. STRJ334B Hydraulic Motor Flow Map

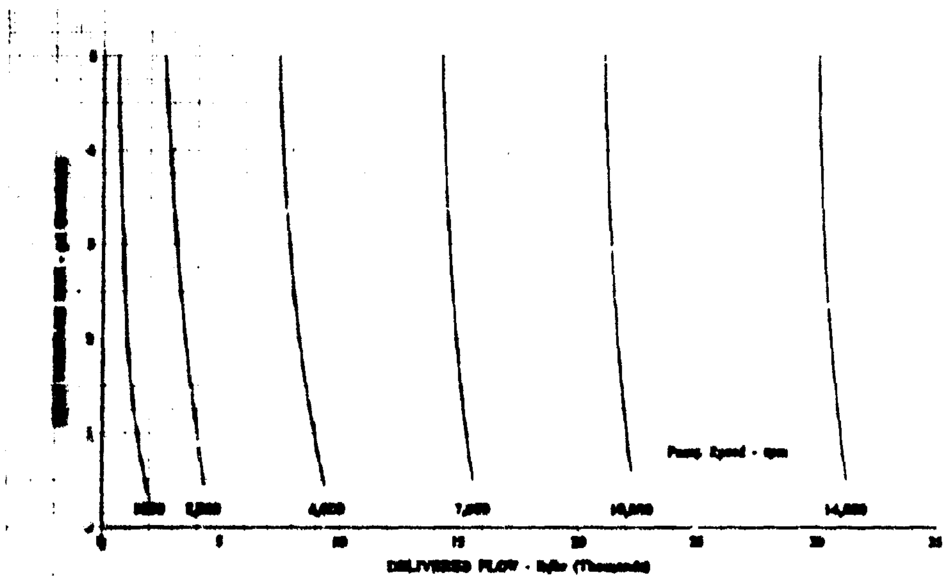


Figure 188. STRJ334B Low Flow Airframe Fuel Boost Pump Map

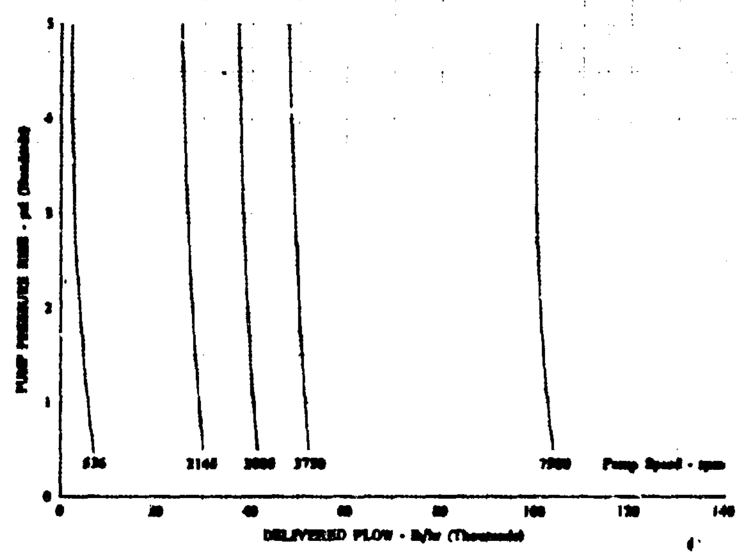


Figure 189. STRJ334B High Flow Airframe Fuel Boost Pump Map

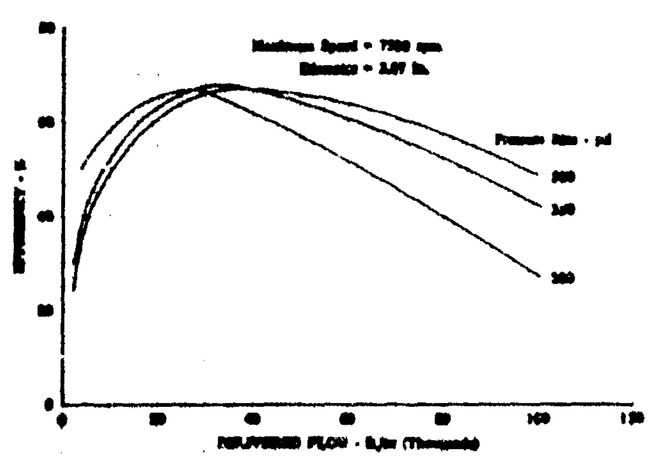


Figure 190. STRJ334B High Flow Vane Pump Performance

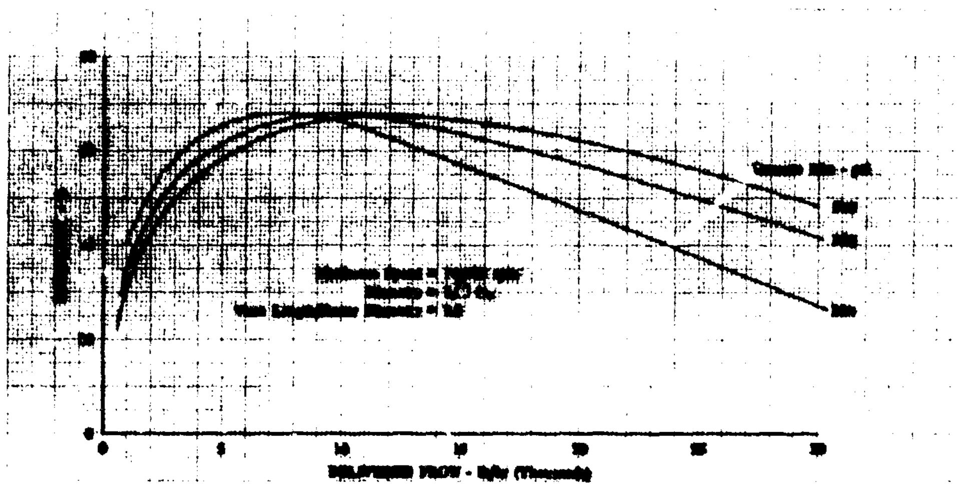


Figure 191. STRJ334B Low Flow Vane Pump Performance

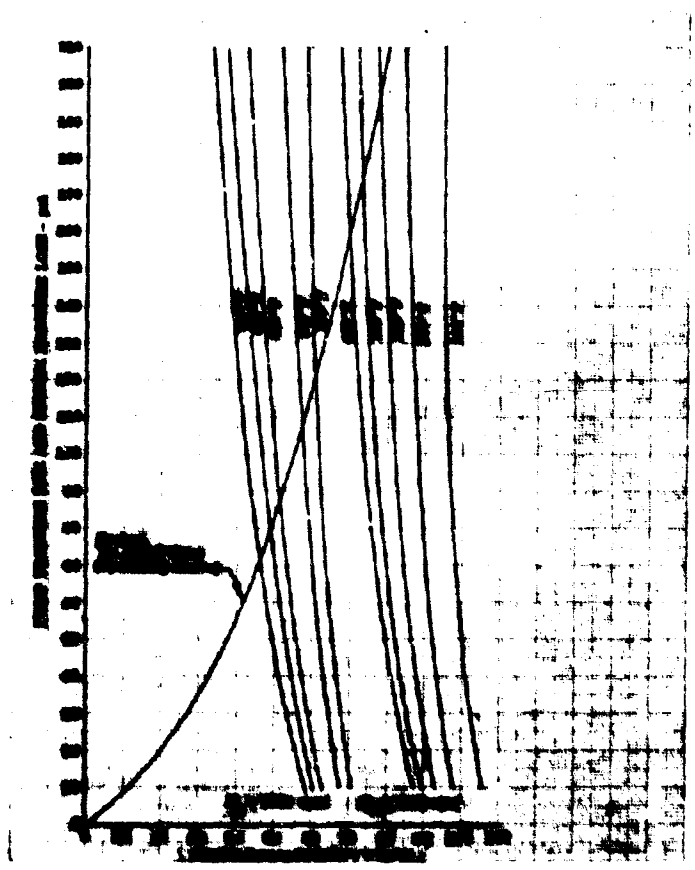


Figure 192. STRJ334B Oil Pump Flow Map

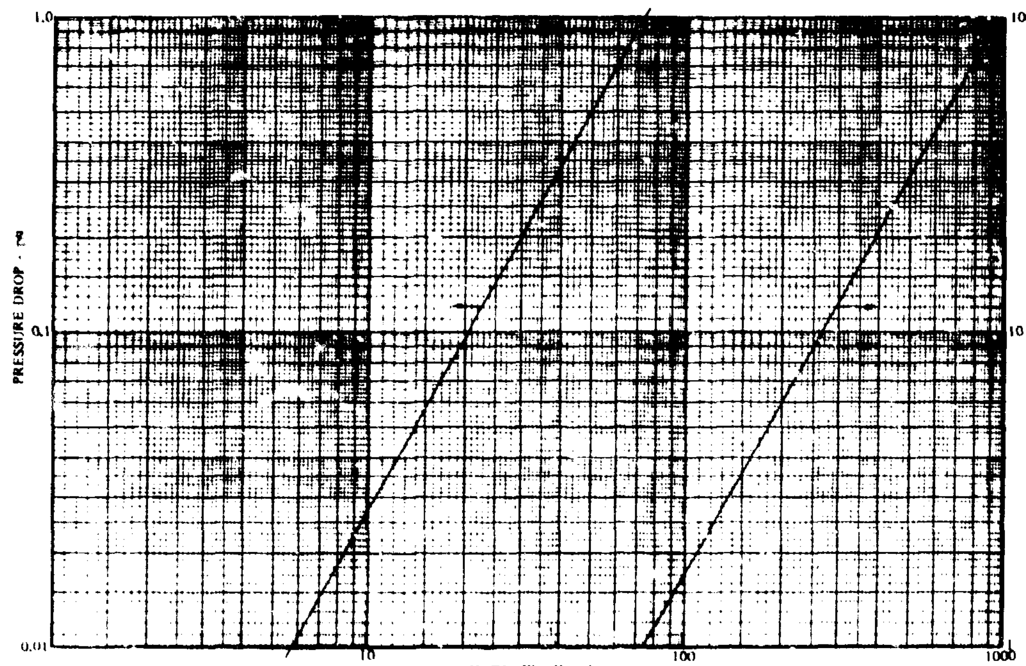


Figure 193. STRJ334B Oil Filter Pressure Drop

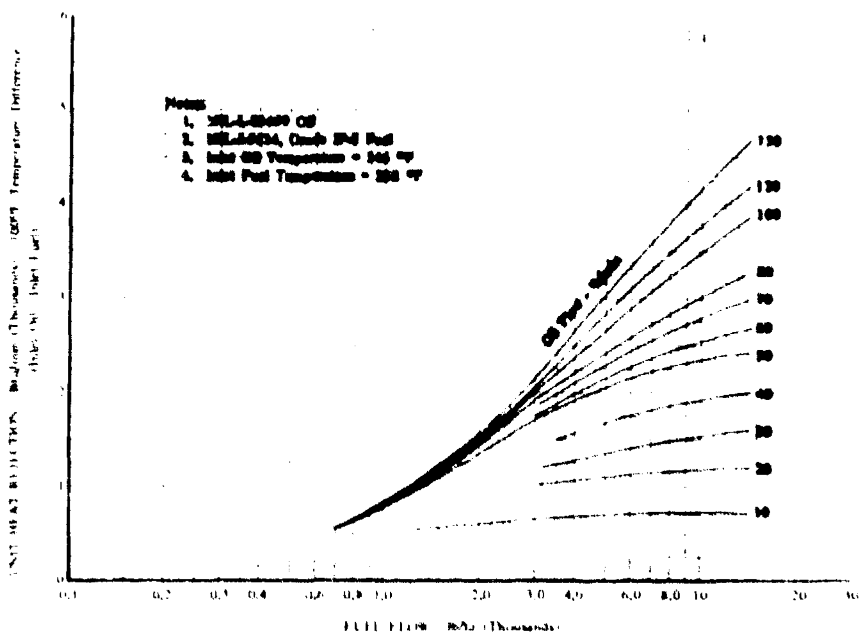


Figure 194. Unit Heat Rejection of STRJ334B Fuel/Oil Cooler

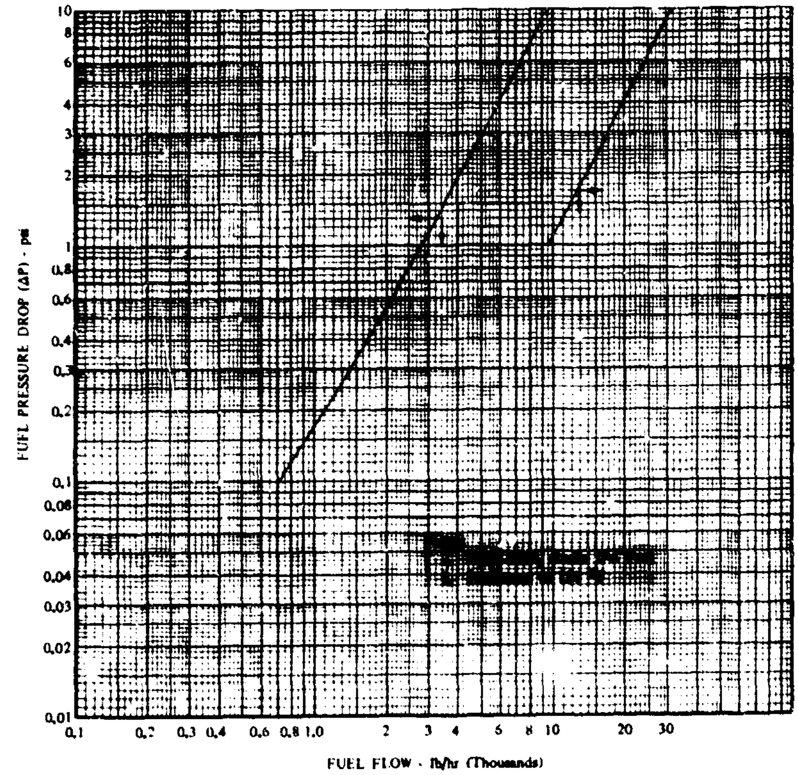


Figure 195. Fuel Side Pressure Drop for STRJ334B Fuel/Oil Cooler

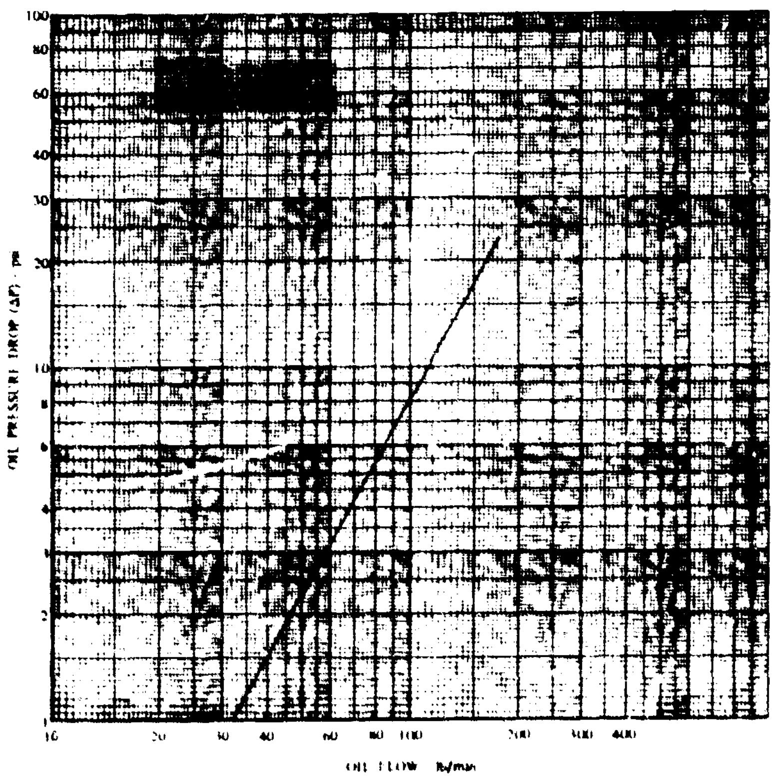


Figure 196. Oil Side Pressure Drop of STRJ334B Fuel/Oil Cooler

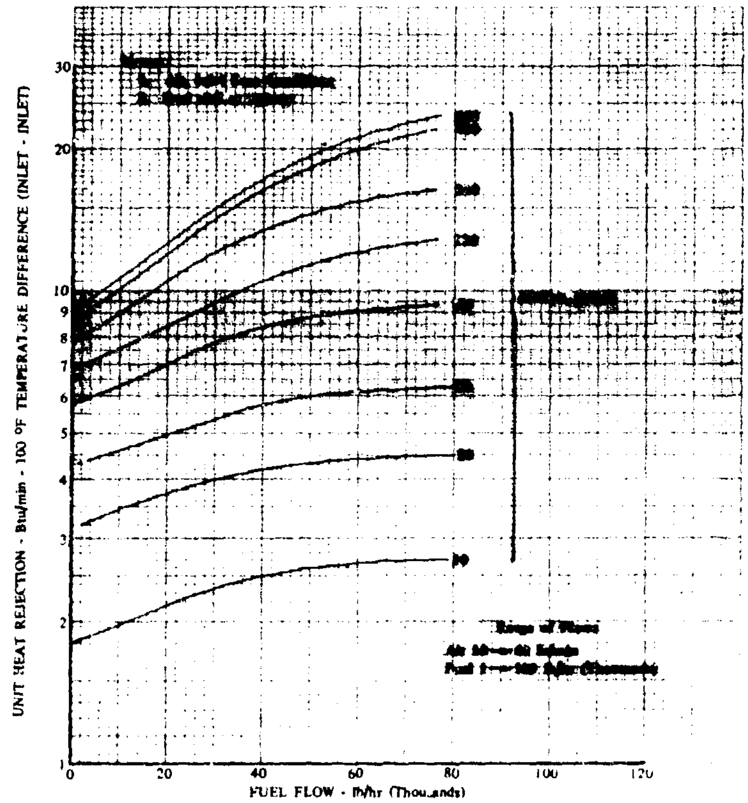


Figure 197. STRJ334B Fuel/Air Heat Exchanger Unit Heat Rejection

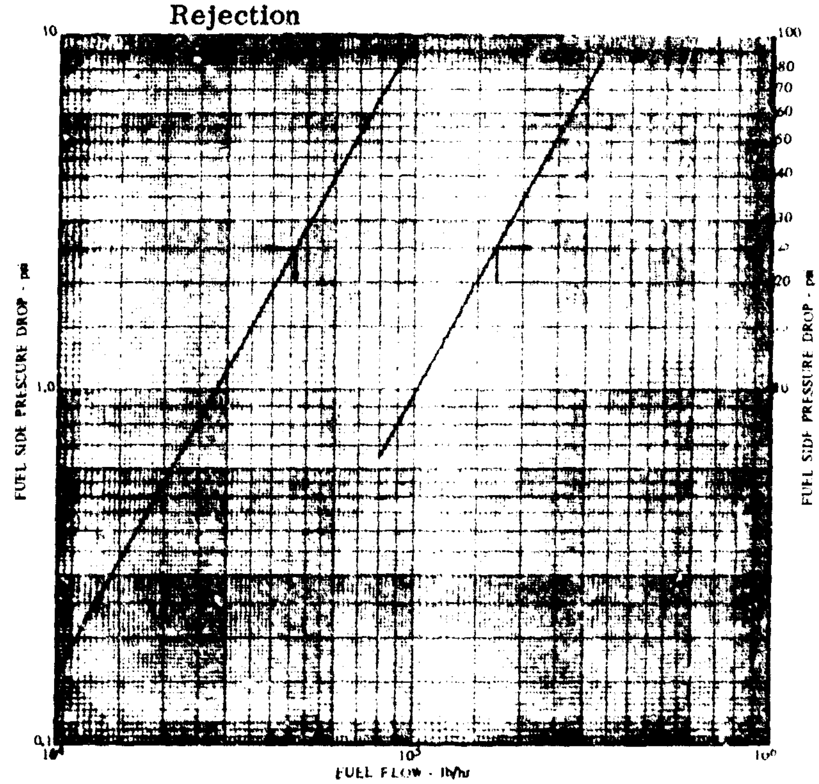


Figure 198. STRJ334B Fuel/Air Heat Exchanger Pressure Drop - Fuel Side (Core)

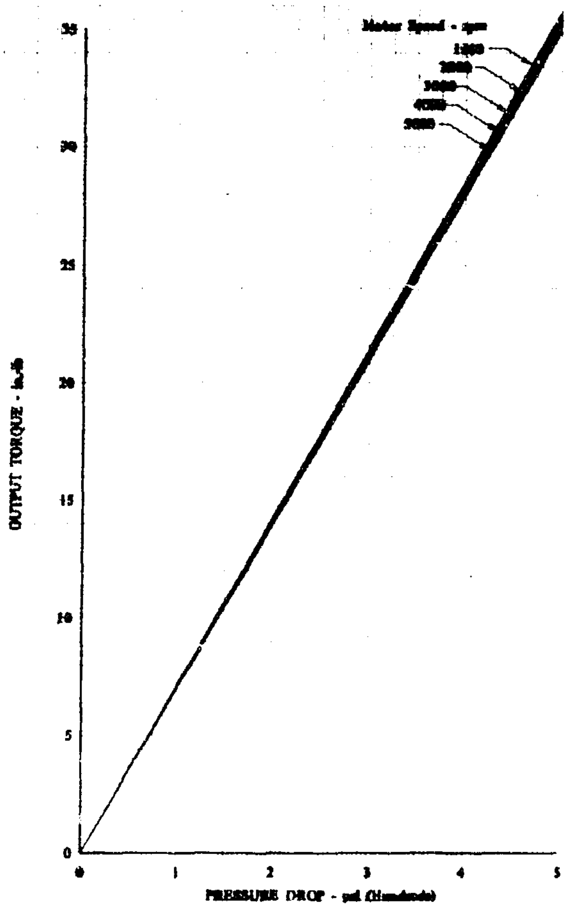


Figure 199. STRJ334B Hydraulic Motor Torque Characteristics

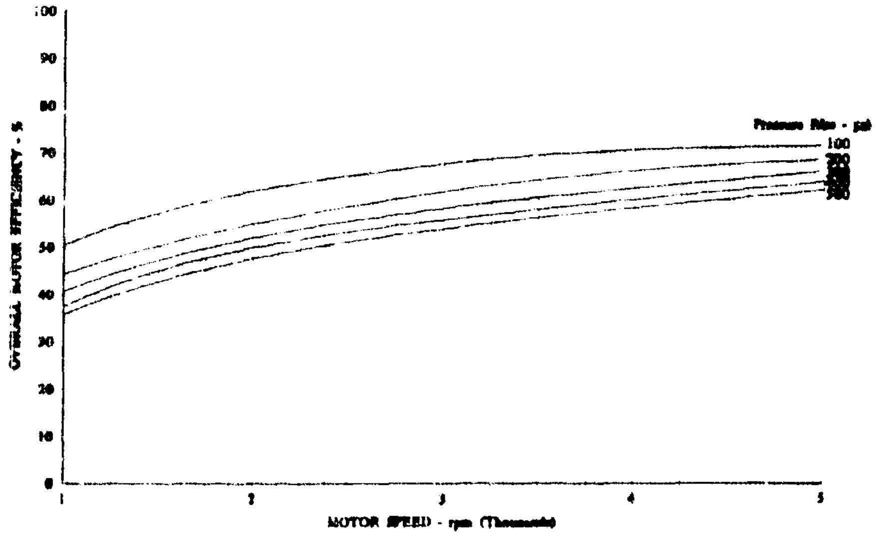


Figure 200. STRJ334B Hydraulic Motor Efficiency Characteristics

APPENDIX IV

FUEL AND LUBRICANT PROPERTIES

Fuel and lubricant properties are shown in tables XXXVI through XLVII.

A. FUEL PROPERTIES

Table XXXVI. Jet Engine Fuels Specific Gravity-Temperature Relationship

Temperature, °F	JP-4	JP-5	JP-6	JP-7	JP-8 and JET A-1
0	0.7860	0.8530	0.7970*	0.8200*	0.8440
50	0.7665	0.8300	0.7810*	0.7990*	0.8225
100	0.7455	0.8110	0.7660	0.7795	0.8050
150	0.7230	0.7900	0.7500	0.7610	0.7855
200	0.6990	0.7700	0.7270	0.7420	0.7665
250	0.6765	0.7500	0.7050	0.7225	0.7490
300	0.6490	0.7295*	0.6835	0.7020	0.7300
350	0.6300*	0.7090*	0.6575*	0.6760	0.7105
400	0.6100*	0.6890*	0.6310*	0.6560	--
450	--	0.6685*	0.6065*	0.6290	--
500	--	0.6480	0.5820*	0.6010	--

*Extrapolated Values.

Table XXXVII. Jet Engine Fuels Viscosity-Temperature Relationship

Temperature, °F	Viscosity, centistokes				
	JP-4	JP-5	JP-6	JP-7	JP-8 and JET A-1
-40	4.4	19.0	--	--	16.28
-30	3.59	13.7	--	10.45	12.01
0	2.4	7.5	2.0	7.0	6.00
77	1.18	2.25	1.25	2.20	2.16
100	1.00	1.95	1.15	1.73	1.71
150	0.84	1.30	0.95	1.35	1.33
200	0.62	0.92	0.81	0.87	0.86
250	0.46	0.70	0.70	0.66	0.69*
300	0.37	0.55	0.59	0.52	0.56*
350	0.33	0.45	--	0.44	0.48*
400	0.27	0.38	--	0.37	0.42*
450	0.23	0.32	--	0.32	0.34*
500	0.21	0.29	--	0.28*	0.30*
	Humble	Humble	AOR Co.	FRDC	FRDC

*Extrapolated Data

Notes: JP-4 and JP-5 Viscosity Data From "Data Book for Designers," Humble Oil & Refining Co., 1969.

JP-5 Data From "Supersonic Fuels and Lubricants," Ashland Oil & Refining Co., 1962.

JP-7 and JET A-1 Viscosity Data From Experimental Work at FRDC.

Table XXXVIII. Jet Engine Fuels Vapor Pressure-Temperature Relationship

Temperature, °F	Vapor Pressure, psia				
	JP-4	JP-5	JP-6	JP-7	JP-8 and JET A-1
50	1.05	--	--	0.008*	--
100	3.00	--	0.25	0.023	0.028
150	6.30	0.14	0.70	0.090	0.14
200	14.00	0.49	1.75	0.31	0.59
250	25.50	1.30	4.00	0.85	1.50
300	40.00	2.50	8.70	2.40	3.60
350	65.00	6.60	16.50	5.50	7.50
400	100.00	14.50	30.00	12.00	15.5*
450	--	25.00	50.00	23.00	32.00*
500	--	--	84.00	42.00	60.00*
	Humble	Humble	AOR Co.	FRDC PWA 535 5/9/67	FRDC

*Extrapolated Data

Notes: JP-4 and JP-5 Data From "Data Book for Designers," Humble Oil & Refining Co., 1969.

JP-6 Data From "Supersonic Fuels & Lubricants," Ashland Oil & Refining Co., 1962.

JP-7 and JET A-1 Data From Experimental Work at FRDC.

Table XXXIX. Jet Engine Fuels Enthalpy-Temperature Relationship

Temperature, °F	Enthalpy, Btu/lb					
	Liquid Phase			Vapor Phase		
	JP-4	JP-5	JP-6	JP-4	JP-5	JP-6
0	0	0	0	160	160	150
50	20	20	20	180	180	170
100	44	42	45	196	198	188
150	70	68	70	216	216	210
200	96	92	95	238	233	235
250	124	120	124	260	260	255
300	152	148	154	280	280	275
350	184	179	182	304	304	300
400	214*	208	213	328	328	325
450	246*	240	245	348	352	350
500	282*	272	280	368	380	380
550	320*	308	314	388	404	410
690	356*	344	350	406	436	440

*Extrapolated Data

Notes: JP-4 and JP-5 Enthalpy Data From "Data Book for Designers," Humble Oil & Refining Co., 1969.

JP-6 Enthalpy Data From "Supersonic Fuels & Lubricants," Ashland Oil & Refining Co., 1962.

Table XL. Jet Engine Fuels Specific Heat-Temperature Relationship

Temperature, °F	Specific Heat, Btu/lb/°F JP-4	JP-5	JP-6	JP-8 and JET A-1
0	0.455	0.435	0.468	0.445
50	0.485	0.460	0.493	0.470
100	0.510	0.485	0.518	0.495
150	0.535	0.510	0.542	0.520
200	0.565	0.535	0.567	0.545
250	0.590	0.560	0.592	0.570
300	0.620	0.585	0.616	0.600
350	0.645	0.615	0.640	0.625
400	0.670	0.640	0.666	0.650
450	0.700	0.665	0.690	0.675
500	0.725	0.690	0.715	0.705

Notes: JP-4, JP-5, and JET A-1 Specific Heat Data From "Data Book for Designers," Humble Oil & Refining Co., 1969.

JP-6 Specific Heat Data From "Supersonic Fuels & Lubricants," Ashland Oil & Refining Co., 1962.

Table XLI. Jet Engine Fuels Average Thermal Conductivity Data

Temperature, °F	Thermal Conductivity, Btu/ft^2 (hr) (°F/°F)
0	0.0816
50	0.0802
100	0.0790
150	0.0776
200	0.0764
250	0.0750
300	0.0738
350	0.0725
400	0.0712
450	0.0699
500	0.0686

Notes: Thermal Conductivity Data From J. B. Maxwell, "Data Book on Hydrocarbons."

Table XLII. Jet Engine Fuels JP-4, JP-5, JET-A, JET-A-1, and Kerosene Thermal Expansion of Liquid at 0 psig and 1000 psig

Temperature, °F	Multiples of Volume at 60°F			
	JP-4		JP-5, JET A-1, JP-8, and Kerosene	
	0 psig	1000 psig	0 psig	1000 psig
100	1.025	1.020	1.020	1.020
150	1.060	1.055	1.050	1.050
200	1.100	1.090	1.080	1.080
250	1.140	1.130	1.110	1.110
300	1.185	1.170	1.145	1.145
350	1.230	1.213	1.180	1.180
400	1.280	1.263	1.220	1.215
450	1.337	1.315	1.263	1.255
500	1.415	1.375	1.313	1.295
550	--	--	1.375	1.340
600	--	--	1.500	1.395

Table XLIII. Hydrogen-Carbon Content and Combustion Characteristics of Jet Fuels

Fuel	Molecular Weight*	Hydrogen, % by Weight	Carbon, % by Weight	Air/Fuel Combustion Ratio**	Combustion Product CO_2, % by Weight**
PWA 523	169	14.85	85.15	17.27	69.93
JP-7 (PWA 535)	177	14.68	85.32	17.19	70.44
JP-8 (PSJ-102)	172	13.48	86.52	16.89	72.42
JP-4	127	14.26	85.74	17.07	71.16
JP-5	170	13.64	86.36	16.91	72.21

*Molecular Weight Calculated From Mid-Boiling Point and ASTM D-875-64 Procedure

**Combustion Ratio and Combustion Product Calculated From Stoichiometric Combustion in Assuming Complete Combustion Where CO_2 and H_2O Are the Only Products

Table XLIV. Physical Characteristics of Jet Engine Fuels

		MIL-T-5624G		MIL-F-25656	MIL-T-38219	MIL-T-83133	
	JET A-1	JP-4	JP-5	JP-6	JP-7	JP-8	PSJ-162
Distillation, °F							
IBP	TBR	TBR	TBR	250 min	360 min	TBR	350 min
10	400 max	TBR	400 max	350 max	385 min	400 max	374 min
20	TBR	290 max	TBR	TBR	403 min	TBR	394 min
50	450 max	370 max	TBR	425 max	TBR	450 max	TBR
90	TBR	470 max	TBR	500 max	500 max	TBR	500 max
EP	550 max	TBR	550 max	TBR	550 max	550 max	550 max
Residue, %, max	1.5 max	1.5	1.5	1.5	1.5	1.5	1.5
Loss, %, max	1.5 max	1.5	1.5	1.5	1.5	1.5	1.5
Calculated V.P., psia							
300°F, max	-	-	-	-	3.0	-	3.5
500°F, max	-	-	-	-	48.0	-	53.0
Reid V.P., psig at 100°F	-	2-3	-	-	-	-	-
Flash Point, °F, min	105 min	-	140	-	140	105 min 150 max	130
Freeze Point, °F, max	-54 max	-72	-51	-65	-46	-51	-45
API GR at 60°F	39-51	45-57	36-48	37-50	44-50	39-51	44-50
SP GR at 60°F	0.8299-0.7753	0.802-0.751	0.845-0.788	0.840-0.780	0.806-0.779	0.830-0.775	0.806-0.779
Sulfur, %/wt, max	0.3	0.4	0.4	0.4	0.1	0.3	0.1
Mercaptan Sulfur, %/wt, max	0.003	0.001	0.001	0.001	0.001	0.001	0.005
Existent Gum, mg/100 ml, max	-	7.0	7.0	5.0	5.0	7.0	7.0
Net Heat of Combustion							
Btu/lb, min	18,400 min	18,400	18,300	18,400	18,700	18,400	18,680
Btu/gal, min	-	-	-	-	124,000	-	124,000
Smoke Point, mm, min	25	-	19.0	20.0	-	25.0	-
Luminometer No., min	45	60	50	-	75	45	70
Aromatics, %/Volume, max	20 max	25.0	25.0	25.0	5	25	5
Olefins, %/Volume, max	-	5.0	5.0	5.0	-	5	-
Copper Strip Corrosion	Slight discoloration	Slight discoloration	Slight discoloration	Slight discoloration	Slight discoloration	Slight discoloration	Slight discoloration
Viscosity, cst, at -30°F, max	15	-	16.5	15 at -40°F	15	15	15
H_2O Tolerance, ml, max	1.0	-	-	1.0	-	-	2
H_2O Reaction, Interface, max	-	1-B	-	1-B	1-B	1-B	-
Thermal Precipitation, 300°F/2	-	-	-	-	Pass	-	Pass
WSIM, min	85	70	85	-	85	-	-
Particulate, matter, max							
Mg/gal, origin	-	4.0	-	-	1.0	1.0 liter	-
Mg/gal, destination	-	8.0	-	-	2.0	-	-
Thermal Stability (Note 1)							
Pressure Change, in. Hg/300 min, max	12	3.0	3.0	10	3	3	5
Preheater Code, max	<3	<3	<3	Light Tan	<3	<3	2

Note 1: Thermal Stability Temperature Parameters

JP-4, JP-5, and JP-8	RT/300°F/400°F/6 lb
JP-6	RT/400°F/500°F/6 lb
JP-7	300°F/500°F/600°F/6 lb
J-162	250°F/400°F/500°F/6 lb
JET A-1	RT/300°F/400°F/6 lb

B. LUBRICANT PROPERTIES

Table XLV. Data for MIL-L-27502 Lubricants

A. Specification Limits		
Specific Gravity 60/60°F	Report	
Viscosity, cSt		
-40°F	15,000 Maximum	
100°F	Report	
210°F	Report	
500°F	1.0 Minimum	
Autoignition Temperature, °F	770 Minimum	
Pour Point, °F	-65 Maximum	
Flash Point, °F	475 Minimum	
Load Carrying Ability, lb/in.	2,550 Minimum	
Evaporation Loss, After 6-1/2 hr, %		
400°F	5.0 Maximum	
500°F	50 Maximum	
Specific Heat, Btu/lb		
140°F	0.40 Minimum	
320°F	0.44 Minimum	
500°F	0.48 Minimum	
Foaming, 60-sec Settling Period		
75°F	None	
200°F	None	
75°F (After 200°F Test)	None	
Corrosion-Oxidation Stability	428°F	464°F
Viscosity Change, %	25 Maximum	100 Maximum
Neutralization Number, mg KOH/g Change	2.0 Maximum	8.0 Maximum
Bearing Deposition		
Bearing Temperature, °F	572	
Bulk Oil Temperature, °F	464	
Oil Inlet Temperature, °F	455	
Test Duration, hr	100	
Overall Demerits	80 Maximum	
Viscosity Change, % at 100°F	100 Maximum	
Filter Deposits, g	2.5 Maximum	
Makeup Rate, ml/hr	36 Maximum	
TAN Change	2.0 Maximum	

Table XLV. Data for MIL-L-27502 Lubricants (Continued)

B. Nominal Properties of Ester Lubricants (Used in Analyses for MIL-L-27502 and Hypothetical Ester)

Density (lb/ft^3) = 64.0 - 0.0254 T (°F)

Viscosity - centistokes

At 100°F	31
At 200°F	5.9
At 300°F	2.2
At 400°F	1.25
At 500°F	0.80

Thermal Conductivity (Btu/ft^2-hr-°F/ft) = 0.808 - 0.000035 T (°F)

Specific Heat (Btu/lb-°F) = 0.315 + 0.0006 T (°F)

Table XLVI. Data for Polyphenyl Ether Lubricants

A. Specification Limits for PWA™ 524

Specific Gravity at 100°F/60°F	1.18 to 1.20
Viscosity, cSt, °F	
100	330 to 375
210	12 to 14
500	1.0 Minimum
Pour Point, °F	+40 Maximum
Refractive Index at 77°F	1.628 to 1.633
Flammability Properties	
Flash Point, °F	525 Minimum
*Fire Point, °F	660
Autogenous Ignition Point, °F	1130 Minimum
Evaporation Loss After 6-1/2 hr, %	
500°F at 140 mm	35 Maximum
Gear Scuffing Load Average, lb/in.	2000 Minimum
Oxidation Corrosion Stability	
Temperature	at 600°F
Weight Change, mg/cm^2	
Inconel X-750	±0.10
Aluminum	±0.10
Titanium	±0.10
M50 Steel	±0.10
WASPALOY®	±0.10
Silver	±0.10
Cobalt L605	±0.10
Viscosity Change, %	
at 100°F	20 Maximum
Foaming, ml	
Sequence 1, Tendency	625 Maximum
Stability	550 Maximum
Sequence 2, Tendency	250 Maximum
Stability	0
Sequence 3, Tendency	625 Maximum
Stability	550 Maximum
Specific Heat, Btu/lb/°F	
Temperature, °F	
300	0.40 Minimum
500	0.45 Minimum
Vapor Pressure, mm Hg	
Temperature, 500°F	3.0 Maximum

Table XLVI. Data for Polyphenyl Ether Lubricants (Continued)

B. Typical PWA™ 524 Lubricant Data Used in the Analysis

Physical Properties	
Molecular Weight	446
Pour Point, °F	40
Flash Point, °F	535
Evaporation Loss, %, 40,000°F, 500°F	31
Load Carrying Ability, lb/in.	2200-2500
Autogenous Ignition Temperature, °F	1150
Vapor Pressure, mm Hg	
At 300°F	0.16
At 350°F	0.32
At 400°F	0.60
At 450°F	1.2
At 500°F	1.9
At 550°F	3.3**
At 600°F	6.5**
Density, g/cm^3	
At 100°F	1.184
At 200°F	1.142
At 300°F	1.100
At 400°F	1.058
At 500°F	1.016
Viscosity, centistokes	
At 100°F	350
At 200°F	16.5
At 300°F	4.2
At 400°F	2.1
At 500°F	1.3
Thermal Conductivity, Btu/ft^2-hr-°F/ft	
At 100°F	0.0768
At 200°F	0.0736
At 300°F	0.0705
At 400°F	0.0674
At 500°F	0.0642
At 600°F	0.0611
Specific Heat, Btu/lb-°F	
At 100°F	0.410**
At 200°F	0.430**
At 300°F	0.450
At 400°F	0.469
At 500°F	0.489

Table XLVI. Data for Polyphenyl Ether Lubricants (Continued)

B. Typical PWA™ 524 Lubricant Data Used in the Analysis (Continued)

*Bearing Rig Test	
Bearing Temperature, °F	650
Bulk Oil Temperature, °F	600
Oil Inlet Temperature, °F	550
After 100 hr	
Overall Demerit Rating	66
Viscosity Change, % at 100°F	64
Increase in Acid Number	nil
Consumption Rate, ml/hr	50
Sludge Formation, g	3.11

C. Typical Properties of 500°F Polyphenyl Ether Derivative (Information Only)

Physical Properties	
Viscosity, centistokes	
At 0°F	13,040
At 100°F	25.20
At 210°F	4.13
At 500°F	0.81
Density, g/cm^3	
At 100°F	1.184
At 500°F	1.017
Bulk Modulus, Isothermal Secant, psi	
At 0°F	500,000
At 100°F	340,000
At 500°F	190,000
Pour Point, °F	-20
Vapor Pressure, mm Hg	
At 700°F	140
At 760°F	760
Flash Point, °F	445
Autogenous Ignition Temperature, °F	940
Specific Heat, Btu/lb-°F	
At 0°F	0.312
At 100°F	0.347
At 200°F	0.383
At 500°F	0.488
Thermal Conductivity, Btu/ft^2-hr-°F/ft	
At 0°F	0.0677
At 100°F	0.0714
At 200°F	0.0720
At 500°F	0.0585
Gear Load Carrying Ability, lb/in.	3020

Table XLVI. Data for Polyphenyl Ether Lubricants (Continued)

C. Typical Properties of 500°F Polyphenyl Ether Derivative (Information Only) (Continued)

Physical Properties (Continued)

Evaporation Loss, 500°F, 700 mm - %	50.7	
140 mm - %	61.0	
Bearing Rig Test		
Bearing Temperature, °F	550	
Bulk Oil Temperature, °F	500	
Oil In Temperature, °F	450	
Overall Demerit Rating	63.2	
Viscosity Change at 100°F, %	54	
TAN Increase	nil	
Consumption Rate, cc/hr	40.8	
Sludge Formation, g	2.26	
Corrosion - Oxidation Test		
Temperature, °F	500	600
Weight Change, mg/cm^2		
Magnesium	+0.03	+0.48
Aluminum	0	-0.22
Titanium	-0.05	+0.16
Iron	+0.04	+0.23
Copper	-3.97	-8.37
Silver	-0.71	-1.39
Viscosity Change at 100°F, %	+6.5	+42.3
Neutralization Number, mg KOH/g Change	+0.09	+0.14
Foaming, ml		
75°F	35	
200°F	0	
75°F	60	

*Typical Properties
**Extrapolated

Table XLVII. Typical Properties of Perfluorinated Polyethers* (Information Only; Not Used in the Analyses)

Property							
Viscosity, cs							
-40°F	8,000	35,000	--	--	--	--	--
-25°F	2,500	9,500	21,000	46,000	--	--	--
0°F	550	1,800	3,500	6,900	13,800	33,000	--
100°F	18	36	55	85	150	270	495
210°F	3.3	5.4	7.6	10.3	16.4	26	43
400°F	0.8	1.1	1.4	1.8	2.7	3.9	6.0
500°F	--	--	--	--	--	2.1	3.0
Viscosity Index, ASTM D2270	23	90	104	113	125	134	145
ASTM Slope	0.844	0.770	0.720	0.686	0.625	0.589	0.549
Pour Point, °F ASTM D92	-70	-50	-50	-45	-35	-30	-20
Density, lb/gal							
75°F	15.5	15.7	15.7	15.8	15.9	15.9	16.0
Density, g/ml							
75°F	1.86	1.88	1.88	1.89	1.90	1.90	1.91
210°F	1.72	1.74	1.75	1.76	1.77	1.77	1.78
400°F	1.52	1.55	1.56	1.57	1.58	1.59	1.60
Thermal Coefficient of Expansion vol vol-°F, Average for 77-210°F(x10^4)	6.1	5.8	--	5.6	--	5.7	5.3
Specific Heat, Btu/lb/°F							
100°F	--	0.243	--	--	--	0.226	--
210°F	--	0.259	--	--	--	0.252	--
Thermal Conductivity, Btu/hr(ft)^2 (°F/ft)							
100°F	--	0.049	--	--	--	0.054	--
300°F	--	0.046	--	--	--	0.051	--
500°F	--	--	--	--	--	0.051	--
Approximate Boiling Range, °F at 0.8 mm hg	289-365	365-410	410-441	441-484	484-518	**	**
Volatility, D972 Mod, wt-% loss, 6-1/2 hr							
300°F	19	2	--	--	--	--	--
400°F	83	26	6	5	1	1	--
500°F	--	93	64	27	19	4	1.4
Flammability				Does not burn			
Isothermal Secant Bulk Modulus, psi							
100°F, 5,000 psig	--	--	--	148,000	--	155,000	--
Surface Tension, dynes/cm							
78.8°F	16.0	16.7	17.7	18.5	18.0	19.6	19.3
Thermal Decomposition Point, °F							
Differential Thermal Analysis	880	880	880	880	880	880	880
Isoteniscope	670	670	670	670	670	670	670
Refractive Index, n_D^{25}	<1.300	<1.300	<1.300	<1.300	<1.300	1.301	1.301
Electrical Properties at Room Temperature							
Dielectric Strength, KV/0.1 in. ASTM D877-49	38.8	41.0	--	51.1	--	41.1	--
Specific Resistivity, Ohm-cm x 10^{-14}, ASTM D257-61	0.64	2.5	--	0.7	--	4.1	--
Dielectric Constant, ASTM D150-59T at 100 KC	2.10	2.12	--	2.44	--	2.15	--
Dissipation Factor, %, ASTM D150-59T at 100 KC	<0.003	<0.006	--	<0.007	--	<0.007	--
Vapor Pressure, mm of Hg (Isoteniscope method used on degassed samples)							
300°F	2.2	0.4	--	0.3	--	--	--
400°F	23.5	4.8	--	2.5	--	0.3	0.1
500°F	145.0	32.0	--	10.3	--	2.9	1.4
600°F	600.0	157.0	--	52.5	--	19.3	9.0
700°F	--	625.0	--	295.0	--	165.0	80.0

*Krytox® 143, E. I. DuPont de Nemours & Co., Inc.
**Incipient decomposition begins before distillation is complete.